植 物 分 类 与 资 源 学 报 2015, **37** (6): 657~682
Plant Diversity and Resources DOI: 10.7677/ynzwyj201515044

横断山区植物的花粉形态及生态意义*

郑 鑫[1], 闵运江[1], 徐 波[2], 孙 航[3], 周忠泽[1**]
(1 安徽大学资源与环境工程学院, 安徽省生物多样性信息中心, 合肥 230601; 2 西南林业大学林学院, 昆明 650204; 3 中国科学院昆明植物研究所, 昆明 650201)

摘要: 应用光学显微镜和扫描电子显微镜对中国西南部横断山区夏季开花的 27 科 43 属 46 种 2 变种植物的花粉形态进行了观察和研究, 并对花粉形态进行了细致的描述。结果表明, 花粉类型以近长球形—长球形和长球形为主, 分别为 27.1%和 25%, 还有少量的为球形, 近球形—近长球形, 近扁球形和四合花粉。萌发孔以 3 孔沟为主, 占 43.8%, 还有 3 沟, 散孔, 多沟, 三拟孔沟, 6-沟, 单沟等类型。外壁纹饰以细网状为主占 50%, 还有粗网状, 细颗粒状, 光滑, 刺状纹饰等。这些物种的孢粉学特征为第四纪地层孢粉研究提供了现代孢粉学依据。此外在花粉形态性状基础上, 通过 SPSS 软件聚类分析, 对部分同科物种间的鉴定特征进行了讨论分析, 并根据植物的生态学特性讨论了它们的生态环境指示意义。

关键词: 花粉形态; 生态意义; 横断山区
中图分类号: Q 944 **文献标志码**: A **文章编号**: 2095-0845(2015)06-657-26

Pollen Morphology of Plants from the Hengduan Mountains and Their Ecological Significance*

ZHENG Xin[1], MIN Yun-jiang[1], XU Bo[2], SUN Hang[3], ZHOU Zhong-ze[1**]
(1 *School of Resources and Environmental Engineering, Anhui University, Anhui Biodiversity Information Center*, Hefei 230601, China; 2 *College of Forestry, Southwest Forestry University*, Kunming 650204, China; 3 *Kunming Institute of Botany, Chinese Academy of Sciences*, Kunming 650201, China)

Abstract: Pollen morphology of selected taxa from the Hengduan Mountains, Southwest China are investigated in the present study. Forty-eight taxa (flowering in the summer, 46 species and 2 varieties) of 43 genera belonging to 27 families were observed by light and scanning electron microscopy. Pollen morphology is described in detail. Two pollen shapes are mainly found in these species: subprolate to prolate (27.1%) and prolate (25%). Spheroidal, subspheroidal to subprolate, suboblate and tetrad shapes can also be found in some species. Aperture type is mostly tricolporate, with a percentage of 43.8, and also contains tricolpate, pantoporate, stephanocolpate, 3-colporoid, 6-colpate, monocolpate. The most common ornamentation is finely reticulate, with a percentage of 50. Other exine ornamentations, such as coarsely reticulate, finely granulate, smooth, spinulose are also observed. The palynological documentation of these species will provide the modern palynological basis for paleopalynological studies of the Quaternary Strata. On the basis of pollen morphology characters, identification features of some species in the same families were discussed according to the results of cluster analysis used by SPSS. The ecological significance was also discussed based on the ecological properties of these taxa.

Key words: Pollen morphology; Ecological significance; Hengduan Mountains

* Funding: The Specialized Research Fund for the Doctoral Program of Higher Education of China (20123401110005), the National Natural Science Foundation of China (41072251) and the State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Palaeontology, CAS, No. 113106)

** Author for correspondence; E-mail: zhzz@ahu.edu.cn
Received date: 2015-03-16, Accepted date: 2015-09-10
作者简介: 郑鑫 (1990-), 女, 硕士研究生, 主要从事生物多样性与保护生态学研究。E-mail: xin5a1102@163.com

The Hengduan Mountains have drawn much attention in the climate and environmental change studies (Li *et al.*, 2012; Kramer *et al.*, 2010; Yao *et al.*, 2015; Ma, 2013). Pollen analysis has been one of the most widely useful and reliable tools to reconstruct paleovegetation and paleoclimate in this region. Studies of modern pollen are the indispensable prerequisite for the fossil pollen interpretation in the same area. The comparison between the modern pollen spectra and the fossil pollen records not only indicates local climate change, but also provides a valuable basis for the restoration of the area's ancient environment. (Tang, 2002; Tang *et al.*, 2009; Li *et al.*, 2006; Zhao *et al.*, 2006).

However, few modern pollen studies have been carried out on the relationship among pollen, vegetation and climate in the Hengduan Mountains. Thus we still lack the modern pollen spectra which could be a background database for better identification of fossil pollen in the Hengduan Mountains, to reconstruct ancient vegetation, palaeoclimate and palaeoenvironment there.

The Hengduan Mountains region which located at the southeastern end of the Tibetan Plateau, is the general term for a chain of parallel mountains running south to north in Sichuan, Yunnan and Eastern Tibet. Covering an area of about 500 000 km^2 (Shi *et al.*, 1998), their elevation gradient is from 2 000 to 6 000 m. With its highly complex geological structure, the region constitutes the transition zone connecting China's eastern Pacific and western ancient Mediterranean areas (Pan, 1989).

The Hengduan Mountains region is the richest area of China in endemic plants and one of the biodiversity hotspots in the world (Boufford *et al.*, 2004). It is estimated that the Hengduan Mountains has more than 9 000 plant species (Yang *et al.*, 2012). It is also a well-known habitat for many modern temperate and alpine plants, especially alpine plants in the genera *Gentiana* L., *Saxifraga* Tourn. ex L., *Saussurea* DC., *Primula* L., etc. (Liu *et al.*, 1986; Wu, 1979, 1980, 1987; Wang, 1992; Li and Li, 1993).

In this study, both light microscopy (LM) and scanning electron microscopy (SEM) were used to examine the pollen morphology of plants from the H-D Mountains in order to:

— describe pollen and document them with LM and SEM micrographs;

— provide modern palynological information for the reconstruction of the paleoclimate and paleoenvironment based on corresponding fossil pollen from Quaternary strata.

1 Material and Methods

1.1 Observation of pollen morphology

In 2011, flowers (flowering in summer) of 46 species and 2 variants of plants belonging to 43 genera of 27 families from the Hengduan Mountains were collected in the field or from ex-situ cultures (Table 1) and then dried. All the species were listed in Table 1 which was based on the concepts of Engler System. The exsiccata were kept in the herbarium of the Department of Ecology, School of Resources and Environmental Engineering, Anhui University, China. The palynological terminology used is according to Punt *et al.* (2007) and Hesse *et al.* (2009).

To prepare them for LM, pollen grains were acetolyzed according to the standard method (Erdtman, 1971): dry anthers were placed in glacial acetic acid for 12 h, incubated in a mixture of concentrated sulphuric acid and acetic anhydride (1:9), and placed in a water bath at 95 ℃ for 5 min and then centrifuged. The supernatant was discharged, and the sediment was washed three times in distilled water and placed in glycerine. The pollen was then embedded in glycerin jelly on glass slides (Wodehouse, 1959). A Leica DME light microscope was used for observations and measurements. Ten regularly shaped and fully expanded pollen grains were measured in each sample. All the measurements were taken under magnification 400×. Generally, for each species, 20 pollen grains were measured, and the mean, maximum and minimum values of P (polar axis), E (equatorial axis) and P/E ratio were recorded to reveal the range of variation. LM

-images were created with a stereoscopic light microscope OLYMPUS BX51 at 1 000 × magnification.

For observation under SEM, pollen grains were extracted from dry anthers, transferred onto stubs, sealed with a drop of nail polish, coated with gold or alloy of platinum and palladium using JFC-1100E sputter, and then observed under the scanning electronic microscopes JSM-6300 at 15-20 kV. The terminology follows Hesse *et al.* (2009), and Kupriyanova and Aleshina (1972).

Table 1　Collection locality information and vouchers for all samples

Order	Family	Species	Vouchers	Location	Altitude/m
Farinosae	Commelinaceae	*Cyanotis vaga*	0908023	Cangshan Mt., Dali, Yunnan, China	2241
Liliflorae	Liliaceae	*Tofieldia divergens*	0908018	Cangshan Mt., Dali, Yunnan, China	2239
Polygonales	Polygonaceae	*Polygonum chinense*	09051	Cangshan Mt., Dali, Yunnan, China	2239
Centrospermae	Caryophyllaceae	*Silene yunnanensis*	0908106	Yulong Snow Mt., Lijiang, Yunnan, China	2859
		S. baccifera	0908014	Cangshan Mt., Dali, Yunnan, China	2239
Ranales	Ranunculaceae	*Delphinium delavayi*	0908034	Cangshan Mt., Dali, Yunnan, China	2181
		Thalictrum delavayi	0908107	Yulong Snow Mt., Lijiang, Yunnan, China	2859
		Anemone hupehensis	0908032	Cangshan Mt., Dali, Yunnan, China	2181
Rosales	Saxifragaceae	*Astilbe rivularis*	0908007	Cangshan Mt., Dali, Yunnan, China	2235
Rosales	Rosaceae	*Sorbaria arborea*	0908113	Baima Snow Mt., Deqin, Yunnan, China	4292
		Potentilia fulgens	0908008	Cangshan Mt., Dali, Yunnan, China	2235
		Spenceria ramalana	0908052	Shangri-La, Yunnan, China	3300
Rosales	Fabaceae	*Cochlianthus montanus*	0908103	Yulong Snow Mt., Lijiang, Yunnan, China	2859
		Pueraria peduncularis	0908003	Cangshan Mt., Dali, Yunnan, China	2235
		Clitoria mariana	0908009	Cangshan Mt., Dali, Yunnan, China	2235
		Vicia cracca	0908020	Cangshan Mt., Dali, Yunnan, China	2239
Sapindales	Celastraceae	*Tripterygium hypoglaucum*	0908013	Cangshan Mt., Dali, Yunnan, China	2239
Sapindales	Balsaminaceae	*Impatiens uliginosa*	0908031	Cangshan Mt., Dali, Yunnan, China	2181
		I. radiata	0908035	Cangshan Mt., Dali, Yunnan, China	2181
		I. procumbens	0908030	Cangshan Mt., Dali, Yunnan, China	2181
		I. delavayi	0908036	Cangshan Mt., Dali, Yunnan, China	2181
	Guttiferae	*Hypericum addingtonii*	0908012	Yulong Snow Mt., Lijiang, Yunnan, China	2810
	Begoniaceae	*Begonia grandis*	0908100	Yulong Snow Mt., Lijiang, Yunnan, China	2856
	Melastomataceae	*Osbeckia crinita*	0908012	Cangshan Mt., Dali, Yunnan, China	2239
	Onagraceae	*Fuchsia hybrida*	0908044	Cangshan Mt., Dali, Yunnan, China	2176
		Oenothera rosea	0908041	Cangshan Mt., Dali, Yunnan, China	2176
	Apiaceae	*Bupleurum longicaule*	0908025	Cangshan Mt., Dali, Yunnan, China	2241
		Heracleum franchetii	0908038	Cangshan Mt., Dali, Yunnan, China	2181
	Ericaceae	*Lyonia ovalifolia*	0908015	Cangshan Mt., Dali, Yunnan, China	2239
Primulales	Primulaceae	*Lysimachia violascens*	0908024	Cangshan Mt., Dali, Yunnan, China	2239
Contortae	Loganiaceae	*Buddleja fallowiana*	0908049	Yulong Snow Mt., Lijiang, Yunnan, China	2875
		B. forrestii	0908037	Cangshan Mt., Dali, Yunnan, China	2181
Contortae	Gentianaceae	*Halenia elliptica*	0908047	Yulong Snow Mt., Lijiang, Yunnan, China	2880
		Gentianopsis paludosa	0908057	Dongda Mt., Zuogong, Xizang, China	5008
Tubiflorae	Labiatae	*Ajuga forrestii*	0908048	Shangri-La, Yunnan, China	3300
		Nepeta wilsonii	0908101	Yulong Snow Mt., Lijiang, Yunnan, China	2856
		Clinopodium megalanthum	0908010	Cangshan Mt., Dali, Yunnan, China	2239
		Elsholtzia rugulosa	0908111	Yulong Snow Mt., Lijiang, Yunnan, China	2891
Tubiflorae	Scrophulariaceae	*Verbascum thapsus*	0908050	Yulong Snow Mt., Lijiang, Yunnan, China	2868
		Pedicularis tenuisecta	0908027	Cangshan Mt., Dali, Yunnan, China	2241
		P. gruina	0908113	Yulong Snow Mt., Lijiang, Yunnan, China	2890
Tubiflorae	Bignoniaceae	*Incarvillea arguta*	0908040	Cangshan Mt., Dali, Yunnan, China	2176
	Acanthaceae	*Pteracanthus forrestii*	0908102	Yulong Snow Mt., Lijiang, Yunnan, China	2856
Tubiflorae	Valerianaceae	*Valeriana flaccidissima*	0908004	Cangshan Mt., Dali, Yunnan, China	2235
Rubiales	Cucurbitaceae	*Zehneria maysorensis*	0908043	Cangshan Mt., Dali, Yunnan, China	2176
Campanulales	Campanulaceae	*Campanula colorata*	0908026	Cangshan Mt., Dali, Yunnan, China	2241
		Lobelia doniana	0908033	Cangshan Mt., Dali, Yunnan, China	2181
Campanulales	Compositae	*Saussurea stella*	0908055	Dongda Mt., Zuogong, Xizang, China	5008

1.2 Cluster analysis

A matrix with 48 species per 6 qualitative and quantitative selected palynological characters (Table 2) was built basing on the compiled data (Table 3) and laboratorial analyses. The selection of palynological characters was used to describe pollen morphology of species generally. In order to retain much more information, the selected characters were encoded according to their dimensional types. The quantitative characters were used directly without transformation while the qualitative characters were endowed with nominal values (Table 3). Then Hierachical cluster analysis was conducted on the selected pollen characters codes using the SPSS package (Version 19.0, IBM http://www.ibm.com).

2 Results

2.1 General trends of pollen morphology in the Hengduan Mountains

After observation of the pollen morphology data above, statistical analysis was conducted. The results from plants in the H-D Mountains show that pollen grains are mainly subprolate to prolate and prolate, with the proportions of 27.1% and 25.0%, respectively. Spheroidal, subspheroidal to subprolate, suboblate and tetrad shapes are also found in a few species. Aperatures are mostly tricolporate, amounting to 43.8%, rarely tricolpate, pantoporate, polyplicate, etc. The majority of ornamentations are finely reticulate, amounting to 50.0%, a few species having an ornamentation that is coarsely reticulate, finely granulate, smooth, spinulose, etc (Appendix).

2.2 Pollen morphology

Under LM, pollen types are presented in plates I-IV, pollen types and their ornamentation under SEM are presented in plates V-VII.

Commelinaceae

Cyanotis D. Don

Cyanotis vaga (Pl. I: 1; Pl. V: 1)

Pollen grains 46.6 (25.0-60.0)×23.1 (10.0-32.5) μm, prolate to perprolate, P/E=2.01 (1.45-2.86). Equatorial view elliptical, ends upwards, nearly cymbiform. Polar view circular or elliptical. Aperture monocolpate, anacolpus narrow. Exine 2.0 μm thick, sexine 1.5 times as thick as nexine. Columellae distinct. Ornamentation: finely reticulate under LM; regulate-perforate under SEM.

Liliaceae

Acorus L.

Tofieldia divergens Bur. and Franch. (Pl. I: 2; Pl. V: 2)

Pollen grains, 21.5 (20.0-25.0)×16.8 (15.0-17.5) μm, prolate, P/E=1.28 (1.14-1.5). Equatorial view elliptical. Polar view circular. Aperture monocolpate, anacolpus narrow. Exine 1.0 μm, sexine equal to nexine. Columellae indistinct. Ornamentation: finely reticulate under LM and under SEM.

Polygonaceae

Polygonum L.

P. chinense L. var. *paradoxum* (Levl.) A. J. Li (Pl. I: 3, 4)

Pollen grains 52.5 (47.5-55.0) μm in diameter, spheroidal. Equatorial view circular. Polar view 3-lobed circular. Apertures 3-colpate, colpus short. Exine 7.0 μm thick, sexine 4 times as thick as nexine. Columellae developed. Ornamentation: coarsely reticulate under LM, reticulation big and distinct, lumina containing 4-10 smaller columellae.

Table 2 Pollen characters and the code of qualitative characters

Number	Characters and code	Measure
1	Length of polaraxis	scale
2	With of equatorial axis	scale
3	P/E	scale
4	Type of aperture: monocolpate(0)/3-colporate(1)/3-colpate(2)/3-porate(3)/4-colpate(4)/4-colporate(5)/5-porate(6)/pantoporate(7)/6-colpate(8)/3- colporoid(9)/2- syncolpate(10)	nominal
5	Ornamentation(LM): reticulate(0)/granulate(1)/smooth(2)/spinulose(3) microreticulato- striate(4)/granulate-perforate(5)	nominal

Caryophyllaceae

Silene L.

Silene yunnanensis Franch. (Pl. I: 5)

Pollen grains 51.8 (47.5–57.5) μm in diameter, spheroidal. Aperture pantoporate, porus, usually 20–28, circular, 4.0–5.0 μm in diameter, interporal distance 7.0–9.0 μm. Exine 4.0 μm thick, sexine 3 times as thick as nexine. Ornamentation:

Table 3　List of the selected pollen characters, followed by their respective codes

Species	Length of polaraxis /μm	With of equatorial axis /μm	P/E	Type of aperture	Ornamentation (LM)
	1	2	3	4	5
Cyanotis vaga	46.6	23.1	2.01	0	0
Tofieldia divergens	21.5	16.8	1.28	0	0
Polygonum chinense	52.5	52.5	1	2	0
Silene yunnanensis	51.8	51.8	1	7	1
S. baccifera	41.8	41.8	1	7	1
Delphinium delavayi	40	30	1.33	2	1
Thalictrum delavayi	25.5	25.5	1	7	1
Anemone hupehensis	26	23.5	1.09	2	1
Astilbe rivularis	15.5	12.3	1.27	1	0
Sorbaria arborea	21.8	19.8	1.1	1	0
Potentilla fulgens	24.75	21	1.17	1	0
Spenceria ramalana	29.5	19.25	1.53	1	0
Cochlianthus montanus	34.6	26.7	1.3	1	0
Pueraria peduncularis	35	31	1.12	1	0
Clitoria mariana	42.7	42.7	1	6	0
Vicia cracca	34.6	26.7	1.44	1	0
Tripterygium hypoglaucum	30	27.1	1.1	1	0
Impatiens uliginosa	41.4	26	1.59	4	0
I. radiata	35.5	22.5	1.56	4	0
I. procumbens	41.4	27	1.53	4	0
I. delavayi	41.3	29.5	1.4	4	0
Hypericum addingtonii	26.8	22.8	1.18	1	0
Begonia grandis	27.9	13.2	2.11	1	0
Osbeckia crinita	32.5	25.5	1.27	1	2
Fuchsia hybrida	55	55	1	3	0
Oenothera rosea	109	109	1	3	4
Bupleurum longicaule	24	14	1.71	1	0
Heracleum franchetii	46.5	18.8	2.48	1	0
Lyonia ovalifolia	35	35	1	1	0
Lysimachia violascens	30.8	20.5	1.5	1	0
Buddleja fallowiana	21.6	14.7	1.47	5	0
B. forrestii	24.5	19.5	1.25	5	0
Halenia ellipticala	38.8	36.5	1.06	1	0
Gentianopsis paludosa	17.3	15.5	1.11	1	0
Ajuga forrestii	26.4	20.9	1.26	2	0
Nepeta wilsonii	56.8	44.3	1.28	8	0
Clinopodium megalanthum	47.8	36.3	1.31	8	0
Elsholtzia rugulosa	28.9	20	1.44	8	0
Verbascum thapsus	28.5	22.8	1.25	9	0
Pedicularis tenuisecta	28.3	16.3	1.74	10	2
P. gruina	36.8	30.8	1.19	10	2
Incarvillea arguta	24.5	19.5	1.25	8	5
Pteracanthus forrestii	101.6	61.6	1.65	1	0
Valeriana flaccidissima	45.5	41.3	1.1	2	3
Zehneria maysorensis	58	49	1.18	1	0
Campanula colorata	25.5	25.5	1	3	3
Lobelia doniana	44.3	31.3	1.42	1	0
Saussurea stella	66.7	60	1.11	1	3

finely granulate under LM.

Silene baccifera (L.) Roth (Pl. I: 6, Pl. V: 3)

Pollen grains 41.8 (40.0-45.0) μm in diameter, spheroidal. Apertures pantoporate, porus usually 10-16, circular, 3.0-4.0 μm in diameter, interporal distance 6.0-8.0 μm. Exine 6.0 μm thick, sexine 3 times as thick as nexine. Ornamentation: finely granulate under LM, microechinate under SEM.

Ranunculaceae

Delphinium L.

Delphinium delavayi Franch. (Pl. I: 7, 8; Pl. V: 4)

Pollen grains 40.0 (37.5-42.5)×30.0 (27.5-32.5) μm, P/E=1.33 (1.15-1.41), subprolate to prolate. Equatorial view oblong. Polar view 3-lobed circular. Apertures 3-colpate, colpus margins indistinct, membrane containing granule. Exine 2.0 m thick, sexine equal to nexine. Exine rather thick at poles. Columellae indistinct. Ornamentation: finely granulate under LM, microechinate under SEM.

Thalictrum L.

Thalictrum delavayi Franch. (Pl. I: 9, 10, 11)

Pollen grains 25.5 (22.5-27.5) μm in diameter, spheroidal. Apertures pantoporate, porus usually 6-7, circular, 1.0-2.5 μm in diameter, interporal distance 4.0-4.5 μm. Exine 2.0 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: finely granulate under LM.

Anemone L.

Anemone hupehensis Lem. f. *alba* W.T. Wang (Pl. I: 12, 13; Pl. V: 5)

Pollen grains 26.0 (22.5-27.5)×23.5 (20.0-25.0) μm, P/E=1.09 (1-1.25), subspheroidal. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3- colpate, colpus long and slender, extending to the poles, 0.5-1.0 μm wide. Exine 2.0 μm thick, sexine slightly thicker than or equal to nexine. Columellae distinct. Ornamentation: finely granulate under LM, microechinate under SEM.

Saxifragaceae

Astilbe Buch.-Ham. ex D. Don

Astilbe rivularis Buch.-Ham. (Pl. I: 14, 15, 16; Pl. V: 6)

Pollen grains 15.5 (15.0-17.5)×12.3 (10.0-15.0) μm, P/E=1.27 (1.0-1.75), subspheroidal to subprolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, lalongate, 1.0-1.5 μm in diameter. Exine 1.5 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: faintly reticulate under LM; distinct reticulate under SEM.

Rosaceae

Sorbaria (Ser.) A. Br. ex Aschers.

Sorbaria arborea Schneid. var. *subtomentosa* Rehder (Pl. I: 17, 18)

Pollen grains 19.8 (15.0-25.0)×21.8 (17.5-27.5) μm, P/E=1.10 (1.0-1.17), suboblate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, circular, 2.0 μm in diameter. Exine 2.0 μm thick, sexine slightly thicker than nexine. Columellae indistinct. Ornamentation: faintly reticulate under LM.

Potentilla L.

Potentilla fulgens Wall. ex Hook. (Pl. I: 19, 20, 21; Pl. V: 7)

Pollen grains 24.75 (22.5-27.5)×21 (17.5-22.5) μm, P/E=1.17 (1.11-1.29), subprolate to prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, circular, 2.0 μm in diameter. Exine 3.0 μm thick, sexine 1.5 times as thick as nexine. Columellae distinct. Ornamentation: finely reticulate under LM, striate-perforate under SEM.

Spenceria Trimen

Spenceria ramalana Trimen (Pl. I: 22, 23; Pl. V: 8)

Pollen grains 29.5 (20-37.5)×19.25 (12.5-22.5) μm, P/E=1.53 (1.25-1.75), prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and

slender, extending to the poles. Endoaperture-porus, circular, 2.5 μm in diameter. Exine 2.0 μm thick, sexine equal to nexine. Columellae indistinct. Ornamentation: finely reticulate under LM, striate-perforate under SEM.

Fabaceae

Cochlianthus Benth.

Cochlianthus montanus (Diels) Harms (Pl. I: 24, 25)

Pollen grains 34.6 (25.0–67.5)×26.7 (17.5–55.0) μm, P/E=1.30 (1.09–1.57), subprolate to prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, lalongate, 3.0 μm in diameter. Exine 2.5 μm thick, sexine equal to nexine. Columellae indistinct. Ornamentation: finely reticulate under LM.

Pueraria DC.

Pueraria peduncularis (Grah. ex Benth.) Benth. (Pl. I: 26, 27, 28; Pl. V: 9)

Pollen grains 35.0 (22.5–42.5)×31.0 (17.5–37.5) μm, P/E=1.12 (1.06–1.28), subspheroidal to subprolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, rather long. Endoaperture-porus, big and lalongate, 4.0 μm in diameter. Exine 2.5 μm thick, sexine slightly thicker than nexine. Columellae distinct. Ornamentation: finely reticulate under LM and SEM.

Clitoria L.

Clitoria mariana L. (Pl. II: 29, 30; Pl. V: 10)

Pollen grains 42.7 (44.0–63.0) μm in diameter, spheroidal. Aperture 5 (-6)-porate, porus circular, 7.0–8.0 μm in diameter. Exine 2.5 μm thick, sexine thicker than nexine. Columellae distinct. Ornamentation: finely reticualte under LM and SEM.

Vicia L.

Vicia cracca L. (Pl. II: 31, 32; Pl. V: 11)

Pollen grains 34.6 (25.0–67.5)×26.7 (17.5–55.0) μm, P/E=1.44 (1.29–2.0), prolate. Equatorial view elliptical. Polar view nearly 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, rather long, extending to the poles. Endoaperture-porus, circular, 5.0 μm in diameter. Exine 2.5 μm thick, sexine slightly thicker than nexine. Columellae indistinct. Ornamentation: finely reticualte under LM and SEM.

Celastraceae

Tripterygium Hook. f.

Tripterygium hypoglaucum (Levl.) Hutch (Pl. II: 33, 34; Pl. V: 12, 13)

Pollen grains 30.0 (25.0–32.5)×27.1 (25.0–30.0) μm, P/E=1.1 (1.0–1.3), subspheriodal to subprolate. Equatorial view subcircular. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, lalongate. Exine 3.0 μm thick, sexine 4 times as thick as nexine. Columellae developed. Ornamentation: finely reticulate under LM and SEM.

Balsaminaceae

Impatiens L.

Impatiens uliginosa Franch. (Pl. II: 35, Pl. V: 14, 15)

Pollen grains 41.4 (35.0–42.5)×26.0 (25.0–28.8) μm, P/E=1.59 (1.33–1.7), prolate. Equatorial view oblate. Polar view rectangular. Apertures goniotreme, 4-colpate, colpus slender and short. Exine 1.0 μm thick, hierarchy indistinct. Ornamentation: finely reticulate under LM; distinct reticulate with granule under SEM.

Impatiens radiata Hook. f. (Pl. II: 36; Pl. V: 16, 17)

Pollen grains 35.5 (32.5–37.5)×22.5 (17.5–32.5) μm, prolate, P/E=1.56 (1.08–1.86). Equatorial view oblate. Polar view rectangular. Apertures goniotreme, 4-colpate, colpus slender and short. Exine 1.5 μm thick, sexine slightly thicker than nexine. Ornamentation: reticulate under LM; distinct reticulate with few granules under SEM.

Impatiens procumbens Franch. (Pl. II: 37; Pl. V: 18)

Pollen grains 41.4 (37.5–45.0)×27.0 (25.0–30.0) μm, prolate, P/E=1.53 (1.42–1.7). Equatorial view oblate. Polar view rectangular. Aper-

tures goniotreme, 4-colpate, colpus slender and short. Exine 2.0 μm thick, sexine slightly thicker than nexine. Ornamentation: distinct coarsely reticulate under LM and SEM.

Impatiens delavayi Franch. (Pl. II: 38; Pl. V: 19)

Pollen grains 41.3 (40.0-45.0)×29.5 (25.0-32.5) μm, prolate, P/E=1.40 (1.31-1.6). Equatorial view oblate. Polar view rectangular. Apertures goniotreme, 4-colpate, colpus slender and short. Exine 2.0 μm thick, sexine slightly thicker than nexine. Ornamentation: reticulate under LM; distinct reticulate with granule under SEM.

Guttiferae

Hypericum L.

Hypericum addingtonii N. Robson (Pl. I: 39, 40, 41)

Pollen grains 26.8 (20.0-35.0)×22.8 (17.5-30.0) μm, P/E=1.18 (1.0-1.3), subprolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, extending to the poles, 3.0 μm in width. Endoaperture- porus, lalongate, 2.0-2.5 μm in diameter. Exine 2.0 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: faintly reticulate under LM.

Begoniaceae

Begonia L.

Begonia grandis Dryand. subsp. *sinensis* (A. DC.) Irmsch. (Pl. II: 42; Pl. VI: 20)

Pollen grains 69.7 (62.5-75.0)×33.1 (25.0-37.5) μm, P/E=2.11 (1.86-2.5), prolate. Equatorial view elliptical. Polar view triangle. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, lalongate, 4.0 μm in diameter. Exine 1.5 μm thick, sexine equal to nexine. Columellae indistinct. Ornamentation: faintly reticulate under LM; striate-perforate under SEM.

Melastomataceae

Osbeckia L.

Osbeckia crinita Benth. ex C. B. Clarke (Pl. II: 43, 44; Pl. VI: 21)

Pollen grains 32.5 (30.0-35.0)×25.5 (22.5-27.5) μm, P/E=1.27 (1.18-1.44), prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, rather long. Endoaperture-porus, circular, 5.0 μm in diameter. Exine 1.5 μm thick, sexine slightly thicker than nexine. Ornamentation: smooth under LM; granulate under SEM.

Onagraceae

Fuchsia L.

Fuchsia hybrida Hort. ex Sieb. and Voss. (Pl. II: 45, 46, Pl. VI: 22)

Pollen grains 55.0 (32.5-82.5) μm in polar diameter, spheroidal. Equatorial view oblate. Polar view triangular, angles obtuse. Apertures 3-porate, porus big and round, 15.0-18.0 μm in diameter. Exine 2.5 μm thick, sexine and nexine rather thicker at the apertures. Columellae distinct. Ornamentation: finely reticulate under LM; finely reticulate with silk under SEM.

Oenothera L.

Oenothera rosea L. Herpt. ex Ait. (Pl. III: 47; Pl. VI: 23)

Pollen grains 109.0 (100.0-120.0) μm in polar diameter, spheroidal. Equatorial view oblate. Polar view triangular, angles obtuse. Apertures 3-porate, porus big and round, 45.0-50.0 μm in diameter. Exine 7.0 μm thick, sexine and nexine rather thicker at the apertures. Columellae distinct. Ornamentation: faintly microreticulato-striate under LM; granulate-perforate with silk under SEM.

Apiaceae

Bupleurum L.

Bupleurum longicaule Wall. & DC. (Pl. III: 48, 49)

Pollen grains 24.0 (20.0-25.0)×14.0 (10.0-15.0) μm, P/E=1.71 (1.67-2.0), prolate. Equatorial view elliptical. Polar view triangle, angles round. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, lalongate, circular, 2.0-2.5 μm in diameter. Exine 2.0 μm thick, sexine slightly thicker

than nexine. Columellae distinct. Ornamentation: finely reticulate under LM.

Heracleum L.

Heracleum franchetii M. Hiroe (Pl. III: 50, 51; Pl. VI: 24)

Pollen grains 46.5 (42.5-52.5)×18.8 (17.5-20.0) μm, P/E=2.48 (2.25-2.86), perprolate. Equatorial view elliptical. Polar view triangle, angles round. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles. Endoaperture-porus, lalongate, circular, 2.5 μm in diameter. Exine 2.5-3.0 μm thick, sexine slightly thicker than nexine. Columellae distinct. Ornamentation: finely reticulate under LM; striate-perforate under SEM.

Ericaceae

Lyonia Nutt.

Lyonia ovalifolia (Wall.) Drude (Pl. III: 52, 53; Pl. VI: 25)

Pollen grains 35.0 (22.5-45.0) μm in diameter, tetrahedral tetrad or decussate tetrad. Every single pollen grain are subspheroidal with 3-colporate, which shaped as half-colpi due to two neighboring grains of tetrahedral tetrad link together. Exine 1.5 μm thick, sexine slightly thicker than nexine. Columellae indistinct. Ornamentation: finely reticulate under LM; distinct reticulate under SEM.

Primulaceae

Lysimachia L.

Lysimachia violascens Franch. (Pl. III: 54, 55; Pl. VI: 26)

Pollen grains 30.8 (25.0-37.5)×20.5 (17.5-22.5) μm, P/E=1.5 (1.22-1.75), prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long and slender, extending to the poles, 1.0 μm in width. Endoaperture-porus, lalongate, cross with colpus, 3.0 μm in diameter. Exine 1.5 μm thick, sexine slightly thicker than nexine. Columellae distinct. Ornamentation: finely reticulate under LM and SEM.

Loganiaceae

Buddleja (Buddleia auct.) L.

Buddleja fallowiana Balf. F. and W. W. Sm. (Pl. III: 56, 57; Pl. VI: 27)

Pollen grains 21.6 (17.5-22.5)×14.7 (12.5-17.5) μm, P/E=1.47 (1.14-1.8), subprolate to prolate. Equatorial view elliptical. Polar view 4-lobed circular. Apertures 4-colporate. Ectoaperture-colpus, long and slender, extending to the poles, 1.0 μm in width. Endoaperture-porus, lalongate, margins at ends diffuse. Exine 1.5 μm thick, indistinct in layer. Exine at poles thicker than that at equator, nexine slightly thicker than exine. Columellae distinct. Ornamentation: finely reticulate under LM and SEM.

Buddleja forrestii Diels (Pl. III: 58, 59; Pl. VI: 28)

Pollen grains 24.5 (22.5-27.5)×19.5 (17.5-22.5) μm, P/E=1.25 (1.11-1.42), subprolate to prolate. Equatorial view rectangular. Polar view 4-lobed circular. Apertures 4-colporate. Ectoaperture-colpus, short. Endoaperture-porus, lalongate, 5.0-6.0 μm in diameter. Exine 1.5 μm thick, indistinct in layer, exine at poles thicker than that at equator, nexine slightly thicker than exine. Columellae indistinct. Ornamentation: finely reticulate under LM and SEM.

Gentianaceae

Halenia Borkh.

Halenia ellipticala D. Don (Pl. III: 60, 61; Pl. VI: 29, 30)

Pollen grains 38.8 (35.0-45.0)×36.5 (35.0-37.5) μm, P/E=1.06 (1.0-1.2), spheroidal to subprolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, rather long, extending to the poles. Endoaperture-porus, circular, 3.0 μm in diameter, with one crack respectively on the two sides. Exine 2.5 μm thick, sexine slightly thicker than nexine. Columellae indistinct. Ornamentation: finely reticulate under LM, distinct reticulate under SEM.

Gentianopsis Ma

Gentianopsis paludosa (Hook f.) Ma (Pl. III: 62, 63)

Pollen grains 17.3 (10.0-22.5)×15.5 (10.0

-22.5) μm, P/E=1.11 (1.0-1.5), spheroidal to subprolate. Equatorial view elliptical. Polar view 3 (4)-lobed circular. Apertures 3 (4)-colporate. Ectoaperture-colpus, rather long, colpus membrane with granules or tumors. Endoaperture-porus, indistinct. Exine 3.0 μm thick, sexine 2 times as thick as nexine. Columellae developed. Ornamentation: distinct reticulate under LM.

Labiatae

Ajuga L.

Ajuga forrestii Diels (Pl. III: 64; Pl. VII: 31)

Pollen grains 26.4 (15.0-45.0)×20.9 (12.5-35.0) μm, P/E=1.26 (1.12-1.6), subprolate to prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colpate, colpus long, extending to the poles, ends narrow. Exine 2.0 μm, sexine 3 times as thick as nexine. Columellae developed. Exine much thicker at the poles by equatorial view. Ornamentation: finely reticulate under LM and SEM.

Nepeta L.

Nepeta wilsonii Duthie (Pl. III: 65, 66)

Pollen grains 56.8 (50.0-62.5)×44.3 (32.5-55.0) μm, P/E=1.28 (1.1-1.77), subprolate to prolate. Equatorial view elliptical. Polar view 6-lobed circular. Apertures 6-colpate, colpus long, extending to the poles. Exine 2.0 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: distinct reticulate under LM.

Clinopodium L.

Clinopodium megalanthum (Diels) C. Y. Wu and Hsuan ex H. W. Li (Pl. III: 67, 68; Pl. VII: 32)

Pollen grains 47.8 (20.0-57.5)×36.3 (15.0-47.5) μm, P/E=1.31 (1.17-1.89), subprolate to prolate. Equatorial view elliptical. Polar view 6-lobed circular. Apertures 6-colpate, colpus long, extending to the poles. Exine 2.5 μm thick, sexine slightly thicker than or equal to nexine. Columellae developed. Ornamentation: finely reticulate under LM and SEM.

Elsholtzia Willd.

Elsholtzia rugulosa Hemsl. (Pl. III: 69, 70; Pl. VII: 33)

Pollen grains 28.9 (25.0-32.5)×20.0 (17.5-22.5) μm, P/E=1.44 (1.33-1.71), prolate. Equatorial view elliptical. Polar view 6-lobed circular. Apertures 6-colpate, colpus long and slender, extending to the poles, 1 μm wide, ends narrow. Exine 2.0 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: finely reticulate under LM and SEM.

Scrophulariaceae

Verbascum L.

Verbascum thapsus L. (Pl. IV: 71, 72, 73; Pl. VII: 34, 35)

Pollen grains 28.5 (25.0-32.5)×22.8 (15.0-25.0) μm, P/E=1.25 (1.1-1.83), subspheroidal to subprolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporoid. Exine 2.0 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: finely reticulate under LM; distinctly reticulate under SEM.

Pedicularis L.

Pedicularis tenuisecta Franch. ex Maxim. (Pl. IV: 74, 75; Pl. VII: 36, 37)

Pollen grains 28.3 (25.0-30.0)×16.3 (10.0-20.0) μm, P/E=1.74 (1.5-3.0), flat, bilaterally symmetrical. Apertures 2-syncolpate with the ends of two colpi anastomose at the poles, colpus cutting pollen grain into equal halves. Exine 2.0 μm thick. Sexine slightly thicker than nexine. Ornamentation: almost smooth under LM; perforate under SEM.

Pedicularis gruina Franch. ex Maxim. (Pl. IV: 76, 77)

Pollen grains 36.8 (33.0-42.0)×30.8 (27.5-34.0) μm, P/E=1.19 (1.06-1.31), flat, bilaterally symmetrical. Apertures 2-syncolpate with the ends of two colpi anastomose at the poles, colpus cutting pollen grain into equal halves. Exine 2.0 μm thick, sexine slightly thicker than nexine. Columellae indistinct. Ornamentation: almost smooth under LM; perforate under SEM.

Bignoniaceae

Incarvillea Juss.

Incarvillea arguta (Royle) Royle (Pl. IV: 78,

Pl. VII: 38, 39)

Pollen grains 24.5 (22.5−27.5)×19.5 (17.5−22.5) μm, subprolate to prolate, P/E = 1.25 (1.11−1.42). Equatorial view elliptical. Polar view 6 (-7)-lobed circular. Apertures 6 (-7)-colpate, colpus long, extending to the poles, colpus membrane beset with fine and distinct granules. Exine 2.0 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: finely granulate-perforate under LM; microechinate-perforate under SEM.

Acanthaceae

Pteracanthus (Nees) Bremek.

Pteracanthus forrestii (Diels) C. Y. Wu (Pl. IV: 79)

Pollen grains 101.6 (90.0−130.0)×61.6 (42.5−77.5) μm, P/E = 1.65 (1.35−2.12), prolate. Equatorial view elliptical. Polar view 18 (-21)-lobed circular. Apertures 3-colporate and 15−18 pseudocolporate. Ectoaperture-colpus, long and slender. Endoaperture-porus, circular, 3 μm in diameter. Exine 2.5 μm thick, sexine 2 times as thick as nexine. Columellae distinct. Ornamentation: coarsely reticulate under LM, sexine semitectate, reticulate with developed lumina and muri, muri densely comprising equirotal granules.

Valerianaceae

Valeriana L.

Valeriana flaccidissima Maxim. (Pl. IV: 80, 81, 82; Pl. VII: 40)

Pollen grains 45.5 (30.0−62.5)×41.3 (27.5−57.5) μm, subspheroidal to subprolate, P/E = 1.1 (1.0−1.18). Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colpate, colpus long and wide. Exine 3.5 μm thick, sexine equal to nexine. Columellae distinct. Ornamentation: microechinate under LM; sparsely spinulose, 1.3−1.6 μm long under SEM.

Cucurbitaceae

Zehneria Endl.

Zehneria maysorensis (Wight and Arn.) Arn. (Pl. IV: 83, 84; Pl. VII: 41)

Pollen grains 58.0 (50.0−75.0)×49.0 (40.0−55.0) μm, P/E = 1.18 (1.0−1.67), subprolate to prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, colpus short and narrow. Endoaperture-porus, circular, 6.0 μm in diameter. Exine 2.0 μm thick, sexine slightly thicker than nexine. Columellae distinct. Ornamentation: finely reticulate under LM; distinct finely reticulate under SEM.

Campanulaceae

Campanula L.

Campanula colorata Wall. (Pl. IV: 85, 86; Pl. VII: 42, 43)

Pollen grains 25.5 (22.5−27.5) μm, spheroidal. Apertures 3-porate, porus membrane beset with granules. Exine 2.0 μm thick, sexine equal to nexine. Ornamentation: spinulose under LM; prominently spinulose, surface between spinules striate-perforate under SEM.

Lobelia L.

Lobelia doniana Skottsb. (Pl. IV: 87, 88, 89; Pl. VII: 44, 45)

Pollen grains 44.3 (32.5−60.0)×31.3 (25.0−35.0) μm, P/E = 1.42 (1.29−1.71), prolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, long, extending to the poles. Endoaperture-porus, lalongate. Exine 2.5 μm, sexine slightly thicker than or equal to nexine. Columellae distinct. Ornamentation: finely reticulate under LM and SEM.

Compositae

Saussurea DC.

Saussurea stella Maxim. (Pl. IV: 90)

Pollen grains 66.7 (65.0−70.0)×60.0 (55.0−65.0) μm, P/E = 1.11 (1.07−1.18), subspheroidal to subprolate. Equatorial view elliptical. Polar view 3-lobed circular. Apertures 3-colporate. Ectoaperture-colpus, short. Endoaperture-porus, narrow. Exine 9.0 μm thick (not including spine length). Columellae distinct. Ornamentation: sexine tectate with 4 μm long spinules under LM.

2.3 Q-type Hierarchical cluster and classification

Q-type Hierarchical cluster analysis were con-

ducted using Between-groups Linkage method. Cluster dendrogram of 48 species classified on the basis of the code matrix for 3 quantitative traits and 2 qualitative traits was shown in Fig. 1, which indicated that four major clades (A, B, C, D) were identified at the dissimilarity coefficient of L2 (0.292). Clade A, Clade B and Clade C consisted of the species which belonged to Archichlamydeae mostly. Clade D consisted of the species of Metachlamydeae and Archichlamydeae. Besides, we could found that at the dissimilarity coefficient of L1 (0.242), 6 small clades are all comprised of species in the same family, such as Ranunculaceae, Balsaminaceae, Loganiaceae, Caryophyllaceae, Scrophulariaceae, Labiatae. However, some species in the same family were divided into different clades, such as the Ranunculaceae, Fabaceae, Labiatae etc.

3 Discussion

3.1 Cluster analysis

Pollen morphology has long been used as the evidence for species classification by phytogeographers (Zhang *et al.*, 1990; Carrijo *et al.*, 2013). Pollen grains were not affected by environment easily, and inherited from generation to generation, which could objectively reflect the interspecific relationship (Zhang, 2004; Wu *et al.*, 2011). It was suggested that Ranales, Rosales, Sapindales, Parietales, Myrtiflorae, Umbelliflorae and Cucurbitales could have the closed relationship according to the clade A in the dendrogram above, the pollen grains of which had 3-colporate or 3-colpate apertures mostly. It was supported by relationships in the Engler System. However, the species of other clades didn't show much consistency with phylogentic relationships. It was likely that we didn't get enough characters data and couldn't reveal the relationships between species in different families with pollen morphology method only. We needed to analyze syntheticly combining with pollen morphology, characters of botany and molecular biology methods to discuss relationships between different families further.

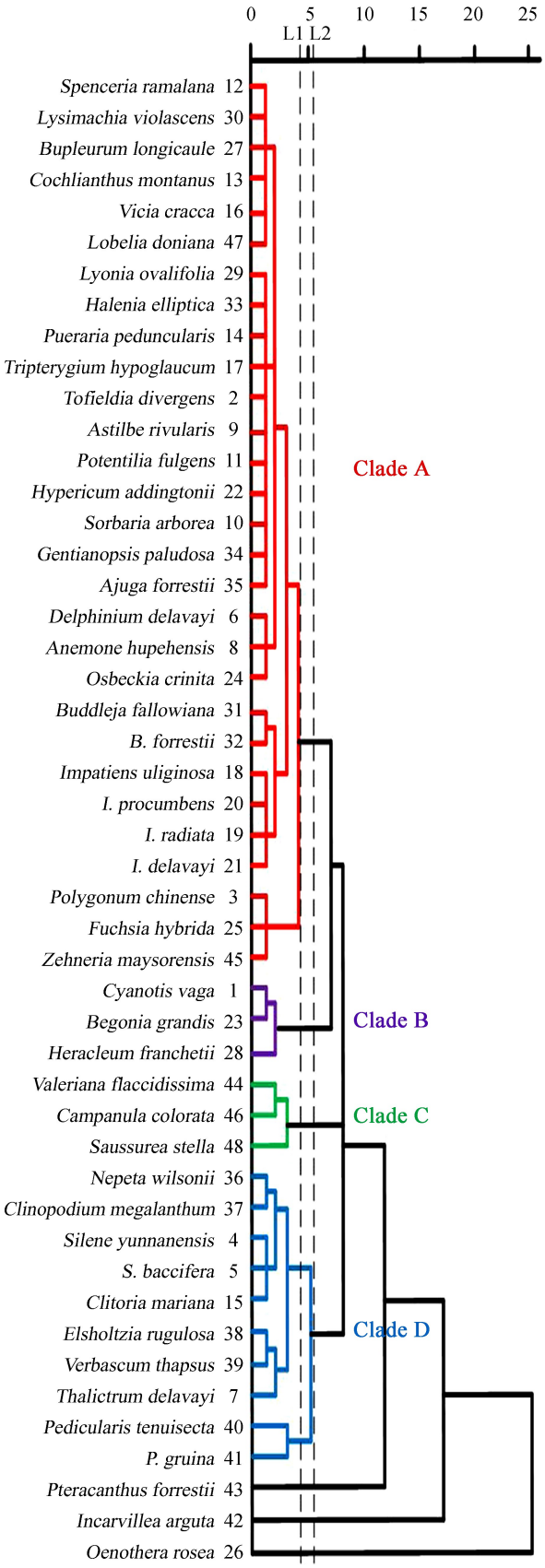


Fig. 1 Dendrogram of 48 species

3.2 Pollen identification features in the same family

Based on the cluster dendrogram above, some species in the same family are divided into different clades. Thus the similarities and dissimilarities of pollen morphology among these species in the same family are provided.

Ranunculaceae pollen is divided into four types basing on apertures. These four types are inaperturate type, 3-colpate type, pantoporate type and stephanocolpate-pantocolpate type, respectively (Wang *et al.*, 1995). Pollen grains of *Delphinium delavayi* and *Anemone hupehensis* both belong to 3-colpate type, and they assemble in a small clade. While pollen grains of *Thalictrum delavayi* have pantoporate apertures and consist in another clade. Description of the three species apertures accord with the results of past studies (Xi and Zhang, 1964; Wang *et al.*, 1995; Yang *et al.*, 1995). Besides, there are some similarities among pollen morphology of the three species: pollen grains subspheroidal to spheroidal, ornamentation finely granulate under LM.

Fabaceae contains three subfamilies. All the four species in this research belong to Papilionoideae (Chen *et al.*, 1994). Their pollen morphology are similar: pollen grains prolate, ornamentation distinct reticulate in LM. Aperture types are the main differences to divide the samples into two clades. Pollen grains of *Cochlianthus montanus*, *Pueraria peduncularis*. and *Vicia cracca* are 3-colporate. While pollen grains of *Clitoria mariana* are 5 (-6)-porate. Wang *et al.* (1995) found that there are also other aperture types such as 3-colpate, 3-porate, and 6-porate except for 3-colporate which is the aperture type of most Fabaceae species. In addition, Ferguson and Skvarla (1979) showed that the *Cranocarpus* genus species have 5-porate aperture.

Labiatae pollen in this research are divided into two main types: 3-colpate type and 6-colpate type. Pollen grains of *Ajuga forrestii* Diels belong to 3-colpate type, while *Nepeta wilsonii*, *Clinopodium megalanthum* and *Elsholtzia rugulosa* belong to 6-colpate type. In addition, *Elsholtzia rugulosa* is separated from *Nepeta wilsonii* and *Clinopodium megalanthum* because of their different pollen grains size. Ornamentation of the four species pollen grains are similar under LM, distinctly reticulate. Hu *et al.* (2012) compared and studied pollen morphology of three genera of Labiatae. They suggested that based on the differences of pollen grains ornamentations and shapes, species of different genera of Labiatae can be classified. Therefore, according to their taxonomic methods, exine ornamentation of pollen grains under SEM of *Clinopodium megalanthum*, *Ajuga forrestii* and *Elsholtzia rugulosa* have shown heteromorphic characteristics, they are reticulate, irregularly reticulate and dually reticulate (small reticulum nested within big lumia) respectively.

Besides, some species in the same family were not classified basing on our selected characters in the cluster dendrogram, since their pollen grains were similar generally, i. e. Balsaminaceae. All the four Balsaminaceae species in this research belong to *Impatiens* L. They possess the same pollen features: pollen grains goniotreme and zygomorphic, 4-colpate. But they are different in the shape and ornamentation. Therefore, according to two taxonomic methods of Cai *et al.* (2007), different types in the species we tested can be identified. Based on the shape of pollen, two types are identified. Pollen grains of *Impatiens uliginosa* are elliptic types, and pollen grains of the other three are rectangular types. Based on the width of muri and lumina, two types are aslo identified. Ornamentation of *Impatiens uliginosa* and *Impatiens radiata* belong to finely reticulate type, and that of *Impatiens delavayi* and *Impatiens procumbens* belong to coarsely reticulate type.

3.3 Ecological significance of main pollen types

Ma *et al.* (2009) made taxonomic identification of Coniferopsida and Compositae pollens which exist broadly in sedimentary strata, and inferred the ecological significance of pollen types according to the ecological properties of these taxa. Yang *et al.* (2013) observed the pollen morphology of nine hygrophyte species from Seven Star Lake area and discussed the

environmental indication significance based on the habitats, origin and distribution of these species. Thus using the similar methods, the ecological significance of the main pollen types are discussed.

Impatiens L. in Balsaminaceae are mainly distributed across Asian tropical and subtropical zones and in Africa. There are about 220 species distributed in China. *Impatiens radiata* grows mostly on shady hillsides or in humid places under forest cover with the altitude of 2 100–3 500 m in the southwestern provinces of China. Because the southwestern China climate is mainly subtropical monsoonal and *I. radiate* grows in a humid and shady habitat of mountains. Therefore, pollen of *I. radiate* can be an indicator for warm and dank climates of the north subtropical zone and also for a medium- and high- mountain environment in southwestern China.

Oenothera L. in Onagraceae are native to America temperate and subtropical zones. There are 19–20 species introduced into China. *Oenothera rosea* grows mostly on grassland and in semi-shady places along ditches with the altitude of 1 000–2 000 m, and this species naturalizes well in Zhejiang, Jiangxi (Lushan Mountain), Yunnan (Kunming), Guizhou Provinces. Because these regions climate are mainly subtropical monsoonal and *O. rosea* grows along ditches. Thus pollen of *O. rosea* may serve as an indicator for warm and humid climates. It can also indicate a medium- and low-mountain environment due to the habitat of *O. rosea* is on the mountains with the altitude of 1 000–2 000 m.

Lyonia Nutt. in Ericaceae are mainly distributed in eastern Asia. There are about 6 species, 5 variants in China. *Lyonia ovalifolia* grows mainly in the forests with the altitude of 700–2 800 m and is distributed in Fujian, Guangdong, Guangxi, Sichuan, Guizhou Provinces, etc. Because these regions climate are mainly subtropical monsoonal and humid. Pollen of *L. ovalifolia* may serve as an indicator for warm and humid climates. Description of *L. ovalifolia* pollen can provide identification characteristic of Ericaceae in Quaternary strata.

Clinopodium L. in Labiatae are mainly distributed in Europe, Central Asia and eastern Asia. There are about 11 species, 6 varieties in China. *Clinopodium megalanthum* grows mainly on hillsides, grasslands, roadsides, and among shrubs and underbrush with the altitude of 1 300–3 200 m, and is distributes in Yunnan Province, southwest of Sichuan Province, southwest of Hubei Province and north of Guizhou Province. Because these regions climate are mainly subtropical monsoonal and humid. Thus pollen of *C. megalanthum* may serve as an indicator for warm and humid climates of the southern subtopical zones.

Pedicularis L. in Scrophulariaceae contains more than 500 species, mainly distributed in the Frigid Zone and high mountains of the Northern Hemisphere. There are about 340 species in China. *Pedicularis tenuisecta* grows mainly in grasslands and on the edges of cypress forests with the altitude of 1 500–3 660 m and is distributes in southwest of Sichuan Province, northwest of Yunnan Province and west of Guizhou Province. Because these regions are mainly high mountains and climate of these region are humid. Thus pollen of *P. tenuisecta* may serve as an indicator for cool and humid climates of the subtropical zone, and also for a cool and humid alpine environment.

Saussurea DC. in Asteraceae are mainly distributed in Asia and Europe. There are about 264 species in China. *Saussurea stella* grows mainly in alpine meadows and on rocky beaches in a cold or dry environment with the altitude of 2 000–5 400 m, and is distributed in areas at high elevation of Gansu, Sichuan, Yunnan and Xizang Province. Therefore, pollen of *S. stella* may act as an indicator for the cool climates, and also for a high mountain environment.

Cyanotis D. Don in Commelinaceae are mainly distributed in the tropical and subtropical zones of Asia and Africa. *Cyanotis vaga* grows mainly on hillside grasslands or under open forest with the altitude below 3 300 m and is distributed in Guangdong, Guizhou, Sichuan, Yunnan Provinces, etc. These regions are mainly subtropical monsoonal and humid. Therefore, pollen of *C. vaga* may serve as an indicator for warm and humid climates in the tropical zone.

Acknowledgements: We should like to thank Mr. John Olsen for his help with the English language.

References:

施雅风 (Shi YF), 李吉均 (Li JJ), 李炳元 (Li BY), 1998. 青藏高原晚新生代隆起与环境变化 [M]. 广州: 广东科学技术出版社

吴学尉 (Wu XW), 王丽花 (Wang LH), 张艺萍 (Zhang YP) 等, 2011. 8 种野生百合的花粉形态及聚类分析 [J]. 江苏农业科学, **39** (3): 197—199

席以珍 (Xi YZ), 张金谈 (Zhang JT), 1964. 银莲花属 (*Anemone* L.) 花粉形态的研究 [J]. 植物学报

张金谈 (Zhang JT), 王萍莉 (Wang PL), 郝海平 (Hao HP), 1990. 现代花粉应用研究 [M]. 北京: 科学出版社

Boufford DE, Dijk PPV, Zhi L, 2004. Mountain of Southwest China [A]// Mittermeier RA, Robles-Gil P, Hoffmann M *et al* eds., *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Ecoregions*, 2nd [M]. Mexico: Cemex, 159—164

Cai XZ (蔡秀珍), Liu KM (刘克明), Cong YY (丛义艳) *et al.*, 2007. SEM Observation on the pollen grains of ten species in *Impatiens* L. (Balsaminaceae) [J]. *Bulletin of Botanical Research*, 279—283

Carrijo TT, Garbin ML, Leite WP *et al.*, 2013. Pollen morphology of some related genera of Vernonieae (Asteraceae) and its taxonomic significance [J]. *Plant Systematics & Evolution*, **299** (7): 1275—1283

Chen DZ (陈德昭), Chen BY (陈邦余), Fang YY (方云忆) *et al.*, 1994. Fabaceae [A]// *Flora Reipubliceae Popularis Sinicae*, Volume 40 [M]. Beijing: Sciences Press

Erdtman G, 1971. *Pollen Morphology and Plant Taxonomy: Angiosperms. An Introduction to Palynology. I* [M]. New York: Hafner Publishing Co, 1—539

Ferguson IK, Skvarla JJ, 1979. The pollen morphology of *Cranocarpus martii* Bentham (Leguminosae: Papilionoideae) [J]. *Grana*, **18**: 15—20

Hesse M, Halbritter H, Zetter R *et al.*, 2009. *Pollen Terminology: An Illustrated Handbook* [M]. New York: Springer Wien, 1—264

Hu Y (胡彦), Ding YF (丁友芳), Wen CX (温春秀) *et al.*, 2012. Study on the pollen morphology of three Genera of Lamiaceae [J]. *Northern Horticulture*, **11**: 60—64

Kramer A, Herzschuh U, Mischke S *et al.*, 2010. Holocene treeline shifts and monsoon variability in the Hengduan Mountains (southeastern Tibetan Plateau), implications from palynological investigations [J]. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **286** (1): 23—41

Kupriyanova LA, Aleshina LA, 1972. *Pollen and Spores of Plants From the Flora of European Part of the USSR. I* [M]. Leningrad: Nauka, 1—171

Li CH (李春海), Tang LY (唐领余), Feng ZD (冯兆东), 2006. A high-resolution late Pleistocene record of pollen vegetation and climate change from Jingning, NW China [J]. *Science in China Series D* (中国科学 D 辑), **36** (5): 453—460

Li XW (李锡文), Li J (李捷), 1993. A preliminary floristic study on the seed plants from the region of Hengduan Mountain [J]. *Acta Botanica Yunnanica* (云南植物研究), **15** (3): 217—231

Li Z, Zhang Q, Ma K, 2012. Tree-ring reconstruction of summer temperature for A. D. 1475-2003 in the central Hengduan Mountains, Northwestern Yunnan, China [J]. *General Information*, **110** (1-2): 455—467

Liu SZ (刘淑珍), Chai ZX (柴宗新), Chen JL (陈继良), 1986. Function of Quaternary Glaciation in the northern Hengduan Mountains [A]// *Special Issue of Hengduan Mounatins Scientific Expedition* (*II*) (横断山考察专集 II) [M]. Beijing: Science and Technology Press

Ma HJ (马宏杰), 2013. Research on Cenozoic stratigraphy and Palaeoenvironmental change in the Hengduan Mountains, Southwest China [D]. Kunming: Kunming University of Science and Technology (昆明理工大学)

Ma YZ (马玉贞), Meng HW (蒙红卫), Sang YL (桑艳礼) *et al.*, 2009. Pollen keys for identification of coniferopsida and compositae classes under light microscopy and their ecological significance [J]. *Acta Palaeontologica Sinica* (古生物学报), **48** (2): 240—253

Pan YS (潘裕生), 1989. Division of geologic structure in the Hengduan mountainous region [J]. *Journal of Mountain Research* (山地研究), **7** (1): 3—12

Punt W, Hoen PP, Blackmore S *et al.*, 2007. Glossary of pollen and spore terminology [J]. *Review of Palaeobotany and Palynology*, **143**: 1—81

Tang LY, 2002. Temporal-spatial distribution of vegetation in the Qinghai-Xizang plateau during the past 12 ka BP [J]. *Journal of Integrative Plant Biology*, **44** (7): 872—877

Tang LY (唐领余), Shen CM (沈才明), Li CH (李春海) *et al.*, 2009. Pollen record of vegetation and environmental changes in the central Tibetan Plateau since the Holocene [J]. *Science in China Series D: Journal of Earth Science* (中国科学 D 辑: 地球科学), **39** (5): 615—625

Wang WC (王文采), 1992. On some distribution patterns and some migration routes found in the Eastern Asiatic region [J]. *Acta Phytotaxonomica Sinica* (植物分类学报), **30**: 1—24

Wang FX (王伏雄), Qian NF (钱南芬), Zhang YL (张玉龙) *et al.*, 1995. *Pollen Flora of China* (中国植物花粉形态) [M]. Beijing: Science Press

Wodehouse RP, 1959. *Pollen Grains: Their Structure, Identification, and Significance in Science and Medicine* [M]. New York: Hafner, 1—1935

Wu ZY (吴征镒), 1979. The regionalization of Chinese flora [J]. *Acta Botanica Yunnanica* (云南植物研究), **1** (1): 1—22

Wu ZY (吴征镒), 1980. *The Vegetation of China* (中国植被) [M]. Beijing: Science Press

Wu ZY (吴征镒), 1987. Origin and Evolution of Flora of Tibet [A] // Wu CY ed., *Flora of Tibet* (Vol. 5) (西藏植物志第5卷) [M]. Beijing: Science Press

Yang YH (杨永红), Yang CG (杨灿光), Cui RZ (崔汝正) *et al.*, 1995. SEM observation of the pollen of genus *Delphinium* in China [J]. *Journal of Yunnan Agricultural University* (云南农业大学学报), **10** (4): 263—267

Yang Z, Yi T, Pan Y *et al.*, 2012. Phylogeography of an alpine plant *Ligularia vellerea* (Asteraceae) in the Hengduan Mountains [J]. *Journal of Systematics and Evolution*, **50** (4): 316—324

Yang X, Zhang R, Jiang H *et al.*, 2013. Pollen morphology and ecological significance of nine hygrophyte species at sevenstar lake area in the bashang area of Hebei Province [J]. *Agricultural Science & Technology*, **14** (7): 962—965

Yao YF, Song XY, Wortley AH *et al.*, 2015. A 22 570-year record of vegetational and climatic change from Wenhai Lake in the Hengduan Mountains biodiversity hotspot, Yunnan, Southwest China [J]. *Biogeosciences*, **12** (5): 1525—1535

Zhang YM (张元明), 2004. Cluster analysis on pollen morphology of the Tamaricaceae from China [J]. *Acta Botanica Boreali-Occidentalia Sinica* (西北植物学报), **24** (9): 1702—1707

Zhao XX (赵秀霞), Zhou ZZ (周忠泽), Wang WG (汪文革), 2006. Pollen morphology and ecological factors of *Alnus trabeculosa* [J]. *Acta Micropalaeontologica Sinica* (微体古生物学报), **23** (4): 419—424

Explanation of Plates

Plate I Pollen morphology and exine ornamentation under LM
1. *Cyanotis vaga*; 2. *Tofieldia divergens*; 3–4: *P. chinense* L. var. *paradoxum*; 5. *Silene yunnanensis*; 6. *Silene baccifera*; 7–8. *Delphinium delavayi*; 9–11. *Thalictrum delavayi*; 12–13. *Anemone hupehensis* Lem f. *alba*; 14–16. *Astilbe rivularis*; 17–18: *Sorbaria arborea* var. *subtomentosa*; 19–21. *Potentilla fulgens*; 22–23. *Spenceria ramalana*; 24–25. *Cochlianthus montanus*; 26–28. *Pueraria peduncularis*. Scales bar 10 μm

Plate II Pollen morphology and exine ornamentation under LM
29–30. *Clitoria mariana*; 31–32. *Vicia cracca*; 33–34. *Tripterygium hypoglaucum*; 35. *Impatiens uliginosa*; 36. *Impatiens radiata*; 37. *Impatiens procumbens*; 38. *Impatiens delavayi*; 39–41. *Hypericum addingtonii*; 42. *Begonia grandis* subsp. *sinensis*; 43–44. *Osbeckia crinita*; 45–46. *Fuchsia hybrida*. Scales bar 10 μm

Plate III Pollen morphology and exine ornamentation under LM
47. *Oenothera rosea*; 48–49: *Bupleurum longicaule*; 50–51. *Heracleum franchetii*; 52–53. *Lyonia ovalifolia*; 54–55. *Lysimachia violascens*; 56–57. *Buddleja fallowiana*; 58–59. *Buddleja forrestii*; 60–61. *Halenia ellipticala*; 62–63: *Gentianopsis paludosa*; 64: *Ajuga forrestii*; 65–66. *Nepeta wilsonii*; 67–68. *Clinopodium megalanthum*; 69–70. *Elsholtzia rugulosa*. Scales bar 10 μm

Plate IV Pollen morphology and exine ornamentation under LM
71–73. *Verbascum thapsus*; 74–75. *Pedicularis tenuisecta*; 76–77. *Pedicularis gruina*; 78. *Incarvillea arguta*; 79. *Pteracanthus forrestii*; 80–82. *Valeriana flaccidissima*; 83–84. *Zehneria maysorensis*; 85–86. *Campanula colorata*; 87–89. *Lobelia doniana*; 90. *Saussurea stella*. Scales bar 10 μm

Plate V Pollen morphology and exine ornamentation under SEM
1. *Cyanotis vaga*; 2. *Tofieldia divergens*; 3. *Silene baccifera*; 4. *Delphinium delavayi*; 5. *Anemone hupehensis* f. *alba*; 6. *Astilbe rivularis*; 7. *Potentilla fulgens*; 8. *Spenceria ramalana*; 9. *Pueraria peduncularis*; 10. *Clitoria mariana*; 11. *Vicia cracca*; 12–13. *Tripterygium hypoglaucum*; 14–15. *Impatiens uliginosa*; 16–17. *Impatiens radiata*; 18. *Impatiens procumbens*; 19. *Impatiens delavayi*

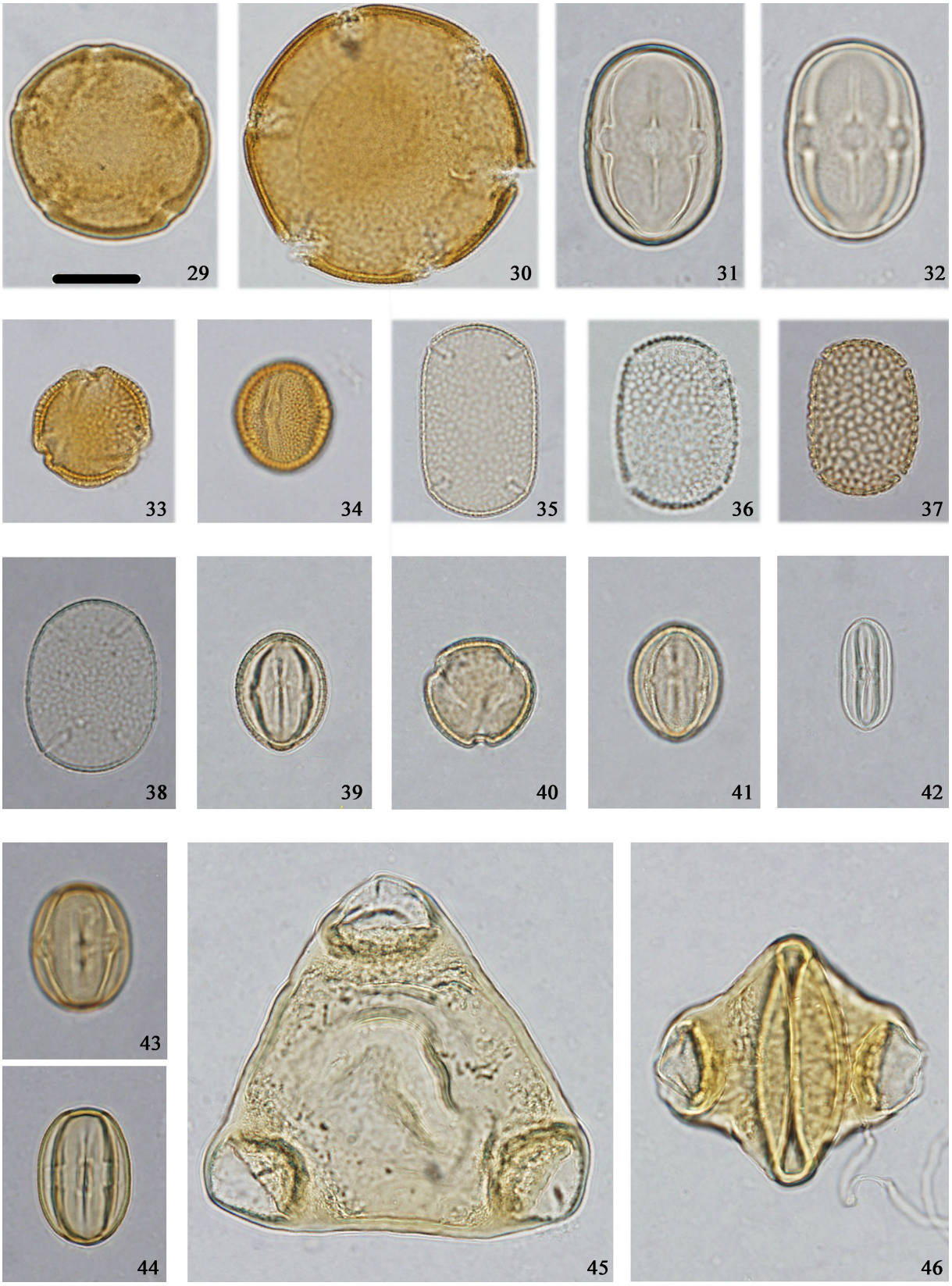
Plate VI Pollen morphology and exine ornamentation under SEM
20. *Begonia grandis* Dryand. subsp. *Sinensis*; 21. *Osbeckia crinita*; 22. *Fuchsia hybrida*; 23. *Oenothera rosea*; 24. *Heracleum franchetii*; 25. *Lyonia ovalifolia*; 26. *Lysimachia violascens*; 27. *Buddleja fallowiana*; 28. *Buddleja forrestii*; 29–30. *Halenia ellipticala*

Plate VII Pollen morphology and exine ornamentation under SEM
31. *Ajuga forrestii*; 32. *Clinopodium megalanthum*; 33. *Elsholtzia rugulosa*; 34–35. *Verbascum thapsus*; 36–37: *Pedicularis tenuisecta*; 38–39. *Incarvillea arguta*; 40. *Valeriana flaccidissima*; 41. *Zehneria maysorensis*; 42–43. *Campanula colorata*; 44–45. *Lobelia doniana*

郑鑫等：图版 I

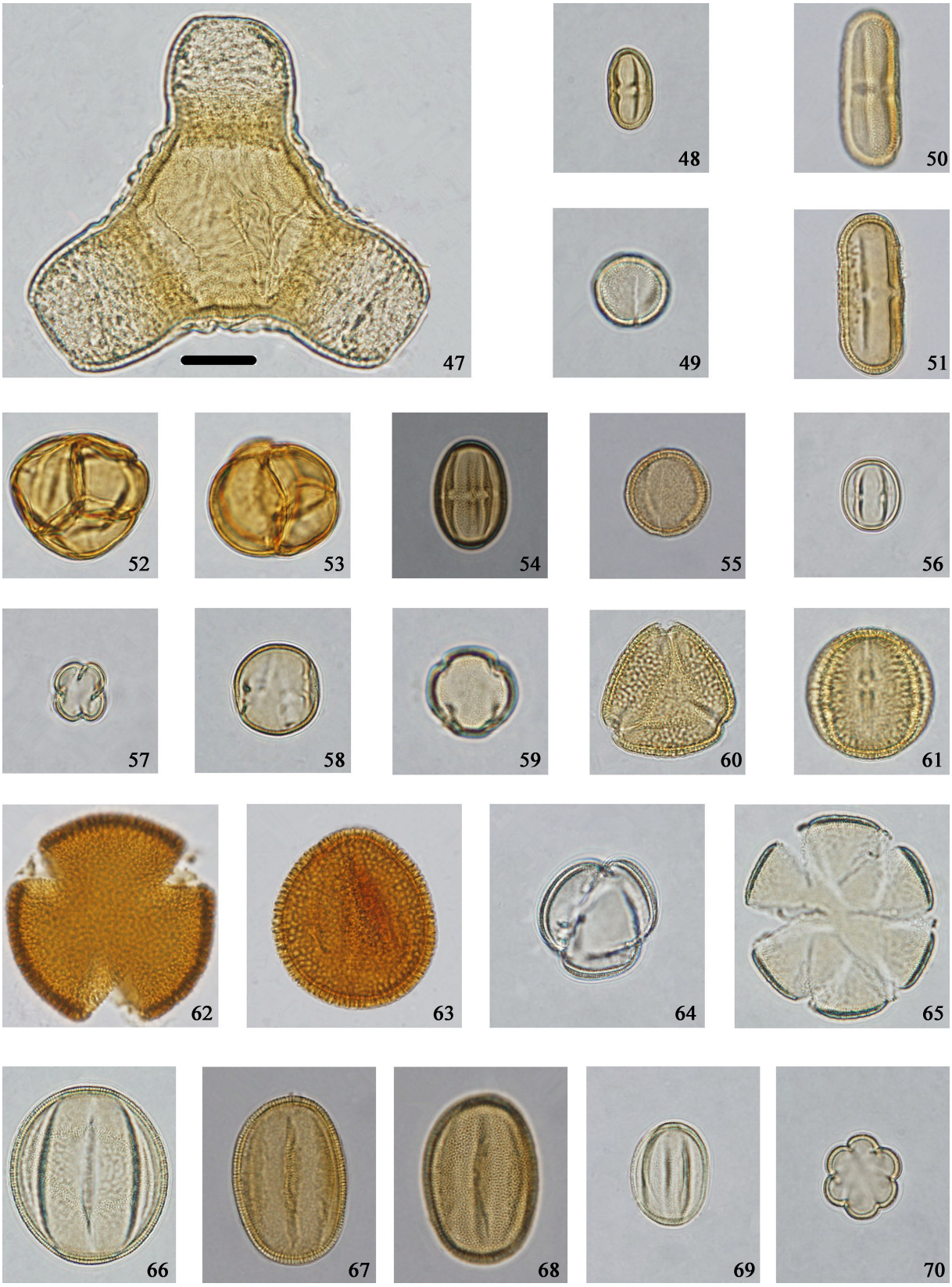
ZHENG Xin *et al.*: Plate I

郑鑫等：图版Ⅱ ZHENG Xin *et al.*: Plate Ⅱ



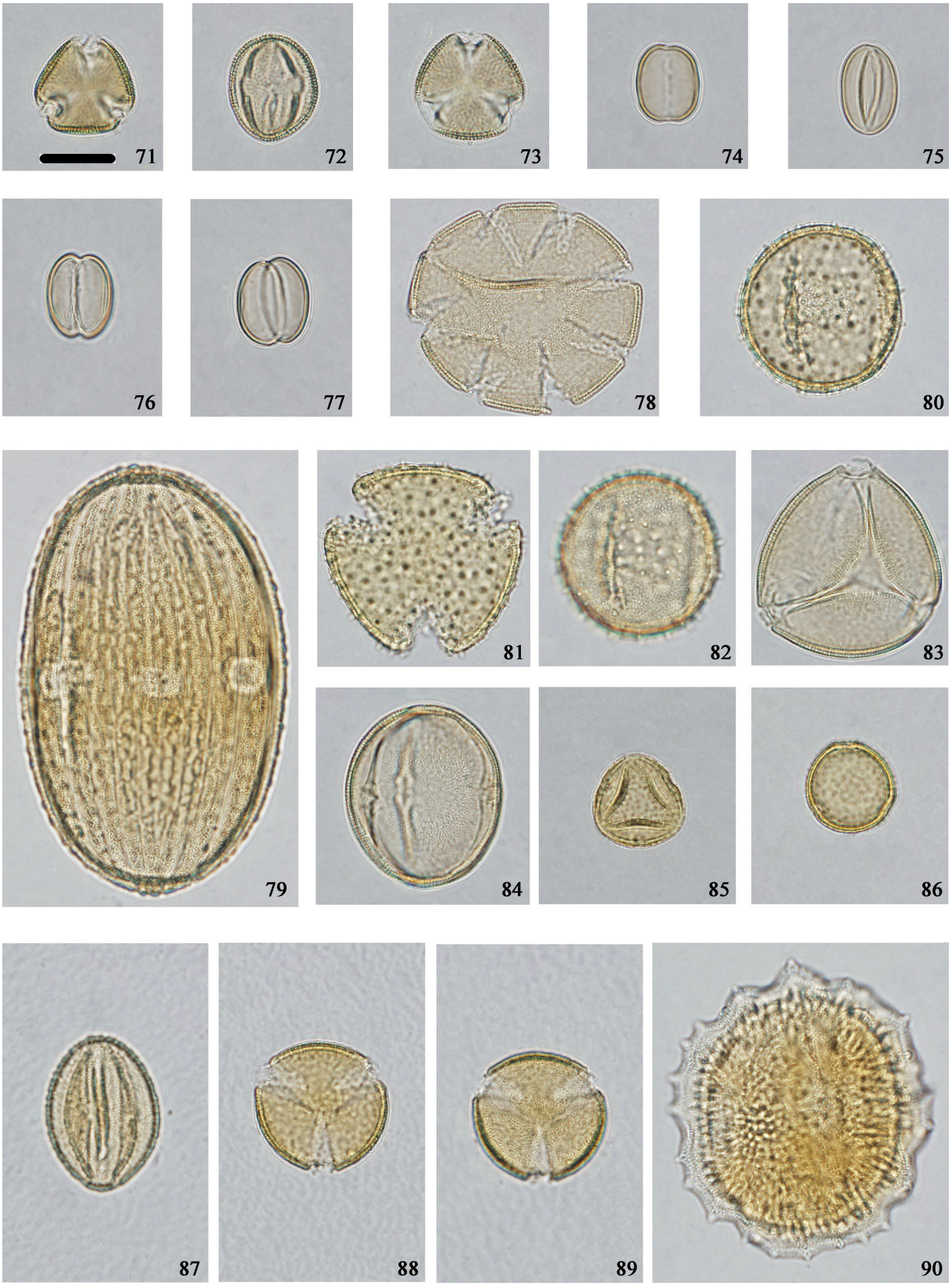
郑鑫等：图版Ⅲ

ZHENG Xin *et al.*: Plate Ⅲ



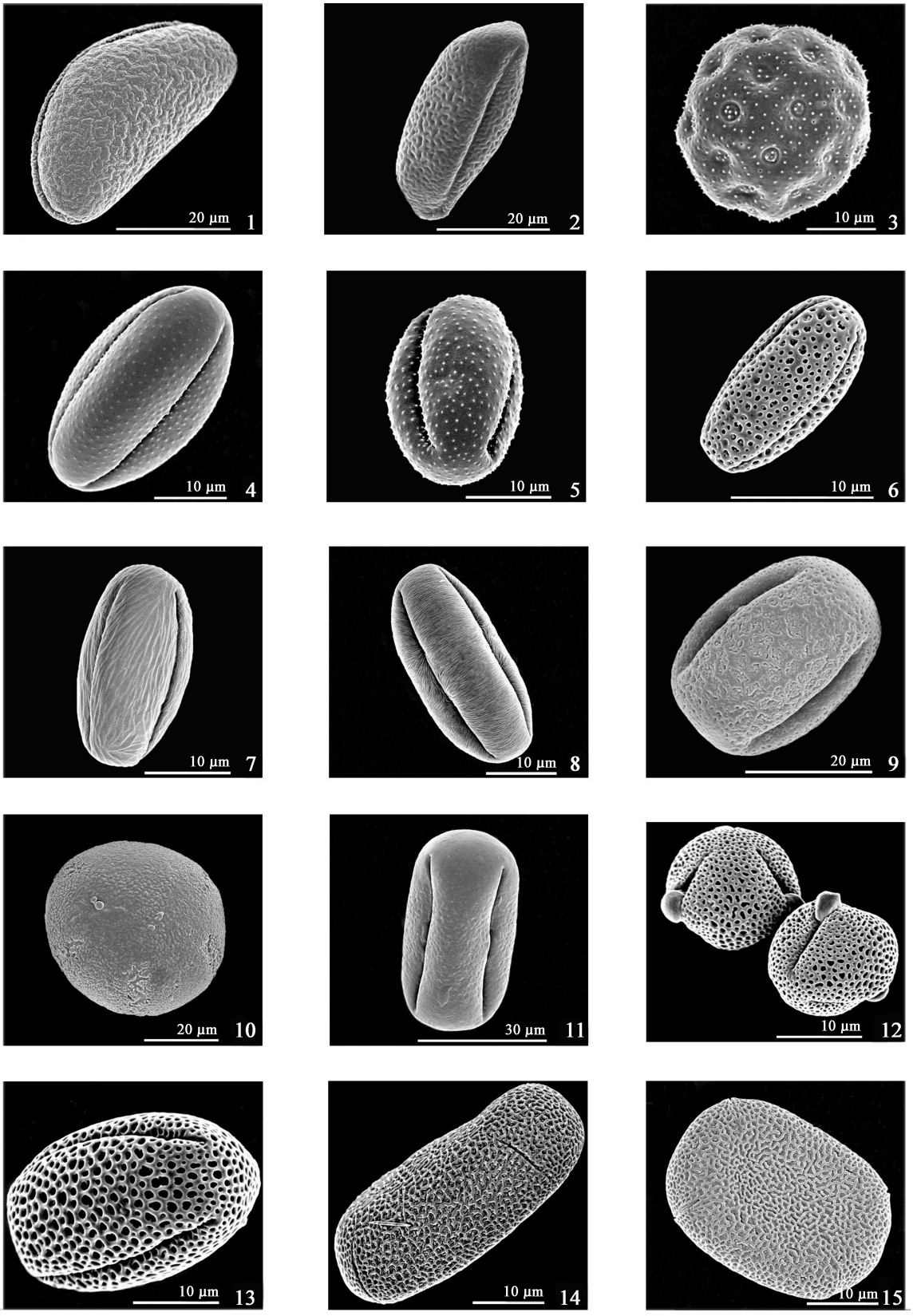
郑鑫等：图版Ⅳ

ZHENG Xin *et al.*: Plate Ⅳ

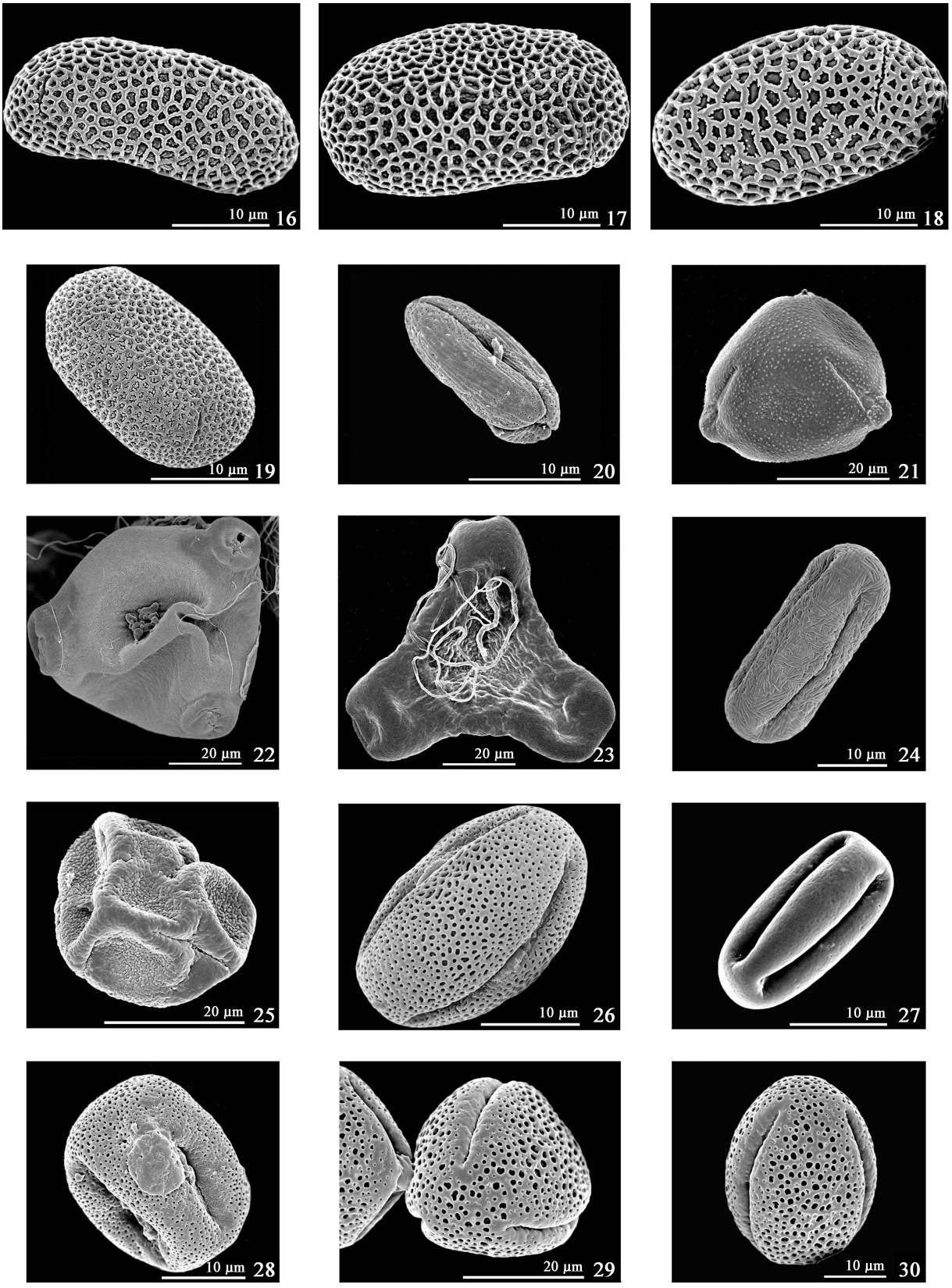


郑鑫等：图版Ⅴ

ZHENG Xin *et al.*: Plate Ⅴ

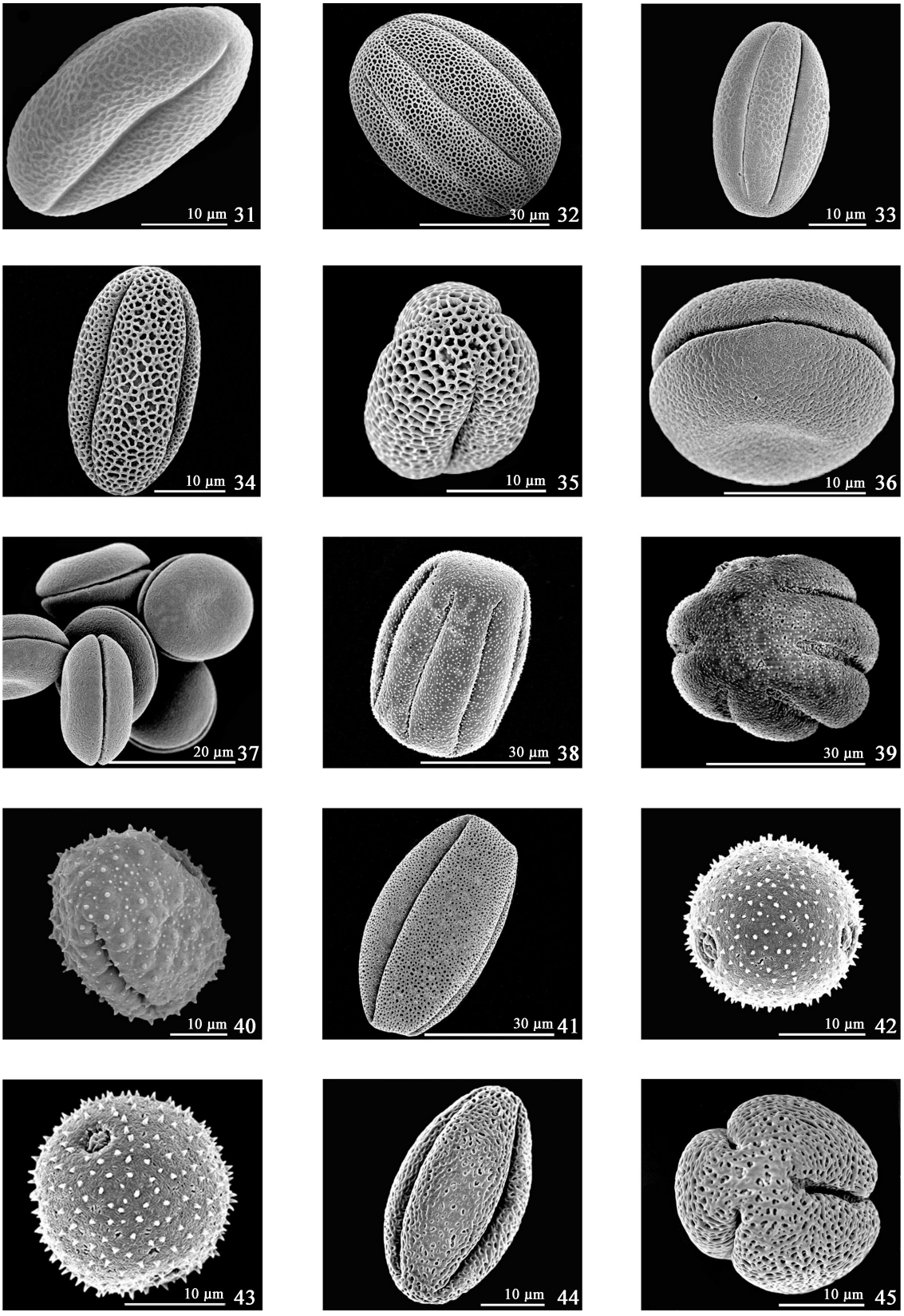


郑鑫等：图版Ⅵ ZHENG Xin *et al.*: Plate Ⅵ



郑鑫等：图版Ⅶ

ZHENG Xin *et al.*: Plate Ⅶ



Appendix Pollen characteristics of investigated species from the Hengduan Mountains

Family	Genus	Species	Shape	Size/μm	Type of aperture	Characteristics of exine				Plate
						Stratification	Thickness /μm	Ornamentation		
								Under LM	Under SEM	
Commelinaceae	*Cyanotis* D.Don	*Cyanotis vaga*	prolate to perprolate	46.6 (25.0–60.0)× 23.1 (10.0–32.5)	monocolpate	2-layered, sexine 1.5 times as thick as nexine	2.0	finely reticulate	regulate-perforate	Pl.I: 1; Pl.V: 1
Liliaceae	*Acorus* L.	*Tofieldia divergens* Bur. and Franch.	prolate	21.5 (20.0–25.0)× 16.8 (15.0–17.5)	monocolpate	2-layered, sexine equal to nexine	1.0	finely reticulate	finely reticulate	Pl.I: 2; Pl.V: 2
Polygonaceae	*Polygonum* L.	*Polygonum chinense* L. var. *paradoxum* (Levl.) A. J. Li	spheroidal	52.5 (47.5–55.0)	3-colpate	2-layered, sexine 4 times as thick as nexine	7.0	coarsely reticulate		Pl.I: 3,4
Caryophyllaceae	*Silene* L.	*Silene yunnanensis* Franch.	spheroidal	51.8 (47.5–57.5)	pantoporate	2-layered, sexine 3 times as thick as nexine	4.0	finely granulate		Pl.I: 5
		S. baccifera (L.) Roth	spheroidal	41.8 (40.0–45.0)	pantoporate	do	6.0	finely granulate	microechinate	Pl.I: 6, Pl.V: 3
Ranunculaceae	*Delphinium* L.	*Delphinium delavayi* Franch.	subprolate to prolate	40.0 (37.5–42.5)× 30.0 (27.5–32.5)	3-colpate	2-layered, sexine equal to nexine	2.0	finely granulate	microechinate	Pl.I: 7,8; Pl.V: 4
	Thalictrum L.	*Thalictrum delavayi* Franch.	spheroidal	25.5 (22.5–27.5)	pantoporate	2-layered, sexine equal to nexine	2.0	finely granulate		Pl.I: 9,10,11
	Anemone L.	*Anemone hupehensis* Lem. f. *alba* W. T. Wang	subspheroidal	26.0 (22.5–27.5)× 23.5 (20.0–25.0)	3-colpate	2-layered, sexine slightly thicker than or equal to nexine	2.0	finely granulate	microechinate	Pl.I: 12,13; Pl.V: 5
Saxifragaceae	*Astilbe* Buch.-Ham. ex D.Don	*Astilbe rivularis* Buch.-Ham.	subspheroidal to subprolate	15.5 (15.0–17.5)× 12.3 (10.0–15.0)	3-colporate	2-layered, sexine equal to nexine	1.5	faintly reticulate	distinct reticulate	Pl.I: 14,15,16; Pl.V: 6
Rosaceae	*Sorbaria* (Ser.) A.Br. ex Aschers.	*Sorbaria arborea* Schneid. var. *subtomentosa* Rehder	suboblate	19.8 (15.0–25.0)× 21.8 (17.5–27.5)	3-colporate	2-layered, sexine slightly thicker than nexine	2.0	faintly reticulate		Pl.I: 17,18
	Potentilla L.	*Potentilla fulgens* Wall. ex Hook.	subprolate to prolate	24.75 (22.5–27.5)× 21 (17.5–22.5)	3-colporate	2-layered, sexine 1.5 times as thick as nexine	3.0	finely reticulate	striate-perforate	Pl.I: 19,20,21; Pl.V: 7
	Spenceria Trimen	*Spenceria ramalana* Trimen	prolate	29.5 (20–37.5)× 19.25 (12.5–22.5)	3-colporate	2-layered, sexine equal to nexine	2.0	finely reticulate	do	Pl.I: 22,23; Pl.V: 8
Fabaceae	*Cochlianthus* Benth.	*Cochlianthus montanus* (Diels) Harms	subprolate to prolate	34.6 (25.0–67.5)× 26.7 (17.5–55.0)	3-colporate	2-layered, sexine equal to nexine	2.5	finely reticulate		Pl.I: 24,25
	Pueraria DC.	*Pueraria peduncularis* (Grah. ex Benth.) Benth.	subspheroidal to suboblate	35.0 (22.5–42.5)× 31.0 (17.5–37.5)	3-colporate	2-layered, sexine slightly thicker than nexine	2.5	do	finely reticulate	Pl.I: 26,27,28; Pl.V: 9
	Clitoria L.	*Clitoria mariana* L.	spheroidal	42.7 (44.0–63.0)	5(-6)-porate	do	2.5	do	do	Pl.II: 29,30; Pl.V: 10
	Vicia L.	*Vicia cracca* L.	prolate	34.6 (25.0–67.5)× 26.7 (17.5–55.0)	3-colporate	do	2.5	do	do	Pl.II: 31,32; Pl.V: 11

Appendix continued

Family	Genus	Species	Shape	Size/μm	Type of aperture	Characteristics of exine				Plate
						Stratification	Thickness /μm	Ornamentation		
								Under LM	Under SEM	
Celastraceae	*Tripterygium* Hook. f.	*Tripterygium hypoglaucum* (Levl.) Hutch	subspheriodal to subprolate	30.0 (25.0–32.5)× 27.1 (25.0–30.0)	3-colporate	2-layered, sexine 4 times as thick as nexine	3.0	do	do	Pl.II: 33,34; Pl.V: 12,13
Balsaminaceae	*Impatiens* L.	*Impatiens uliginosa* Franch.	prolate	41.4 (35.0–42.5)× 26.0 (25.0–28.8)	4-colpate	hierarchy indistinct	1.0	do	distinct reticulate	Pl.II: 35, Pl.V: 14,15
		I. radiata Hook. f.	prolate	35.5 (32.5–37.5)× 22.5 (17.5–32.5)	4-colpate	2-layered, sexine slightly thicker than nexine	1.5	reticulate	distinct reticulate with few granules	Pl.II: 36; Pl.V: 16,17
		I. procumbens Franch.	prolate	41.4 (37.5–45.0)× 27.0 (25.0–30.0)	do	do	2.0	coarsely reticulate		Pl.II: 37; Pl.V: 18
		I. delavayi Franch.	prolate	41.3 (40.0–45.0)× 29.5 (25.0–32.5)	do	2-layered, sexine slightly thicker than nexine	2.0	reticulate	distinct reticulate	Pl.II: 38; Pl.V: 19
Guttiferae	*Hypericum* L.	*Hypericum addingtonii* N. Robson	subprolate	26.8 (20.0–35.0)× 22.8 (17.5–30.0)	3-colporate	2-layered, sexine equal to nexine	2.0	faintly reticulate		Pl.II: 39,40,41
Begoniaceae	*Begonia* L.	*Begonia grandis* Dryand. subsp. *sinensis* (A. DC.) Irmsch.	prolate	69.7 (62.5–75.0)× 33.1 (25.0–37.5)	do	do	1.5	do	striate-perforate	Pl.II: 42; Pl.VI: 20
Melastomataceae	*Osbeckia* L.	*Osbeckia crinita* Benth. ex C.B. Clarke	prolate	32.5 (30.0–35.0)× 25.5 (22.5–27.5)	do	2-layered, sexine slightly thicker than nexine	1.5	smooth	granulate	Pl.II: 43,44; Pl.VI: 21
Onagraceae	*Fuchsia* L.	*Fuchsia hybrida* Hort. ex Sieb. and Voss.	spheroidal	55.0 (32.5–82.5)	3-porate	2-layered, sexine and nexine rather thicker at the apertures	2.5	finely reticulate	finely reticulate with silk	Pl.II: 45,46, Pl.VI: 22
Onagraceae	*Oenothera* L.	*Oenothera rosea* L. Herpt. ex Ait.	spheroidal	109.0 (100.0–120.0)	3-porate	2-layered, sexine and nexine rather thicker at the apertures	7.0	faintly microreticulato-striate	granulate-perforate with silk	Pl.III: 47; Pl.VI: 23
Apiaceae	*Bupleurum* L.	*Bupleurum longicaule* Wall. & DC.	prolate	24.0 (20.0–25.0)× 14.0 (10.0–15.0)	3-colporate	2-layered, sexine slightly thicker than nexine	2.0	finely reticualte		Pl.III: 48,49
	Heracleum L.	*Heracleum franchetii* M. Hiroe	perprolate	46.5 (42.5–52.5)× 8.8 (17.5–20.0)	3-colporate	do	2.5–3.0	do	striate-perforate	Pl.III: 50,51; Pl.VI: 24
Ericaceae	*Lyonia* Nutt.	*Lyonia ovalifolia* (Wall.) Drude	tetrahedral tetrad or decussate tetrad	35.0 (22.5–45.0)	3-colporate	do	1.5	do	distinct reticulate	Pl.III: 52,53; Pl.VI: 25
Primulaceae	*Lysimachia* L.	*Lysimachia violascens* Franch.	prolate	30.8 (25.0–37.5)× 20.5 (17.5–22.5)	3-colporate	do	1.5	do	finely reticulate	Pl.III: 54,55; Pl.VI: 26
Loganiaceae	*Buddleja* (Buddleia auct.) L.	*Buddleja fallowiana* Balf. F. and W.W. Sm.	subprolate to prolate	21.6 (17.5–22.5)× 14.7 (12.5–17.5)	4-colporate	2-layered, sexine slightly thicker than nexine	1.5	do	do	Pl.III: 56,57; Pl.VI: 27
		B. forrestii Diels	subprolate to prolate	24.5 (22.5–27.5)× 19.5 (17.5–22.5)	4-colporate	2-layered, sexine slightly thicker than nexine	1.5	finely reticualte	finely reticualte	Pl.III: 58,59; Pl.VI: 28

Appendix continued

Family	Genus	Species	Shape	Size/μm	Type of aperture	Characteristics of exine				Plate
						Stratification	Thickness /μm	Ornamentation		
								Under LM	Under SEM	
Gentianaceae	*Halenia* Borkh.	*Halenia ellipticala* D. Don	subspheriodal to subprolate	38.8 (35.0–45.0)× 36.5 (35.0–37.5)	3-colporate	2-layered, sexine 4 times as thick as nexine	2.5	do	distinct reticulate	Pl.III: 60,61; Pl.VI: 29,30
	Gentianopsis Ma	*Gentianopsis paludosa* (Hook f.) Ma	spheroidal to subprolate	69.7 (62.5–75.0)× 33.1 (25.0–37.5)	3(4)-colporoid	2-layered, sexine 2 times as thick as nexine	3.0	distinct reticulate		Pl.III: 62,63
Labiatae	*Ajuga* L.	*Ajuga forrestii* Diels	subprolate to prolate	26.4 (15.0–45.0)× 20.9 (12.5–35.0)	3-colpate	2-layered, sexine 3 times as thick as nexine	2.0	finely reticulate	finely reticulate	Pl.III: 64; Pl.VII: 31
	Nepeta L.	*Nepeta wilsonii* Duthie	do	56.8 (50.0–62.5)× 44.3 (32.5–55.0)	6-colpate	2-layered, sexine equal to nexine	2.0	reticulate		Pl.III: 65,66
	Clinopodium L.	*Clinopodium megalanthum* (Diels) C.Y. Wu and Hsuan ex H.W. Li	subprolate to prolate	47.8 (20.0–57.5)× 36.3 (15.0–47.5)	do	2-layered, sexine slightly thicker than or equal to nexine	2.5	finely reticulate	finely reticulate	Pl.III: 67,68; Pl.VII: 32
	Elsholtzia Willd.	*Elsholtzia rugulosa* Hemsl.	prolate	28.9 (25.0–32.5)× 20.0 (17.5–22.5)	6-colpate	2-layered, sexine equal to nexine	2.0	finely reticualte	finely reticualte	Pl.III: 69,70; Pl.VII: 33
Scrophulariaceae	*Verbascum* L.	*Verbascum thapsus* L.	subspheroidal to subprolate	28.5 (25.0–32.5)× 22.8 (15.0–25.0)	3-colporoid	2-layered, sexine 3 times as thick as nexine	2.0	do	do	Pl.IV:71,72,73; Pl.VII: 34,35
	Pedicularis L.	*Pedicularis tenuisecta* Franch. ex Maxim.	flat	28.3 (25.0–30.0)× 16.3 (10.0–20.0)	2-syncolpate	2-layered, sexine slightly thicker than nexine	2.0	smooth	perforate	Pl.IV: 74,75; Pl.VII: 36,37
		P. gruina Franch. ex Maxim.	do	36.8 (33.0–42.0)× 30.8 (27.5–34.0)	do	do	2.0	do	do	Pl.IV: 76,77
Bignoniaceae	*Incarvillea* Juss.	*Incarvillea arguta* (Royle) Royle	subprolate to prolate	24.5 (22.5–27.5)× 19.5 (17.5–22.5)	6(-7)-colpate	2-layered, sexine equal to nexine	2.0	finely granulate-perforate	microechinate-perforate	Pl.IV: 78; Pl.VII: 38,39
Acanthaceae	*Pteracanthus* (Nees) Bremek.	*Pteracanthus forrestii* (Diels) C.Y. Wu	prolate	101.6 (90.0–130.0)× 61.6 (42.5–77.5)	3-colporate and 15-18 pseudocolporate	2-layered, sexine 2 times as thick as nexine	2.5	coarsely reticulate		Pl.IV: 79
Valerianaceae	*Valeriana* L.	*Valeriana flaccidissima* Maxim.	subspheroidal to subprolate	45.5 (30.0–62.5)× 41.3 (27.5–57.5)	3-colpate	2-layered, sexine equal to nexine	3.5	microechinate	sparsely spinulose	Pl.IV:80,81,82; Pl.VII: 40
Cucurbitaceae	*Zehneria* Endl.	*Zehneria maysorensis* (Wight and Arn.) Arn.	subprolate to prolate	42.7 (44.0–63.0)	3-colporate	2-layered, sexine slightly thicker than nexine	2.0	finely reticualte	distinct finely reticualte	Pl.IV: 83,84; Pl.VII: 41
Campanulaceae	*Campanula* L.	*Campanula* L.	spheroidal	25.5 (22.5–27.5)	3-porate	do	2.0	spinulose	striate-perforate	Pl.IV: 85,86; Pl.VII: 42,43
	Lobelia L.	*Lobelia doniana* Skottsb.	subprolate to prolate	44.3 (32.5–60.0)× 31.3 (25.0–35.0)	3- colporate	2-layered, sexine slightly thicker than or equal to nexine	2.5	finely reticulate	finely reticulate	Pl.IV:87,88,89; Pl.VII: 44,45
Compositae	*Saussurea* DC.	*Saussurea stella* Maxim.	subspheroidal to subprolate	66.7 (65.0–70.0)× 60.0 (55.0–65.0)	3-colporate	2-layered	9.0	spinulose		Pl.IV: 90